# SELECTIONS
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(PUBLIC WORKS DEPARTMENT.)

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No. XXII.

Official Correspondence

ON THE SUBJECT OF ATTACHING

LIGHTNING CONDUCTORS

TO

POWDER MAGAZINES.

CALCUTTA.
JOHN GRAY, "CALCUTTA GAZETTE" OFFICE
1857

"I have just proved that lightning does not damage buildings on which it falls, when they are provided with proper conductors. These apparatuses, if sufficiently multiplied, are almost certain preservatives. I knew of no case in which their efficacy has failed, in which there have not been immediately discovered palpable errors of construction ; I do not, however, wish to affirm the occurrence of very rare exceptions to be absolutely impossible."—*Arago's Meteorological Essays.*

PREFACE.

The Papers which form this number of the Government Selections, are, for the most part, of a controversial character, and relate to a subject which must be of the greatest interest to the General Public as well as to the Officers attached to the Public Works Department. So long ago as the year 1838 Sir William O'Shaughnessy (the distinguished Superintendent of Electric Telegraphs in India) was requested by the late Military Board to report upon the expediency or otherwise of attaching lightning conductors to Powder Magazines. His report was unfavorable to the adoption of these conductors, as generally constructed and applied; and his adverse opinions were repeated and enforced at great length, and with much ability, in two subsequent reports. The two first of these reports were submitted by the Honorable Court of Directors for the opinions of Professors Faraday and Daniell, and the last report was referred to Professors Faraday and Wheatstone.

These three gentlemen,—all acknowledged Authorities on such subjects,—were strongly in favour of Lightning Conductors, in the efficacy of which they had the utmost confidence; and they combated seriatim all the arguments adduced by Sir William O'Shaughnessy.

It is here but right to explain that the last report of Sir William O'Shaughnessy having been written in the year 1844, it is possible that since then he may have modified his views; but his absence from India at this time is a bar to obtaining his present opinions on the subject. It has not been thought necessary, however, to refrain from the publication of the Papers on these grounds, for the value of such a discussion in the final solution of the important questions at issue cannot but prove very great. The reader who may already believe in the efficacy of lightning conductors, will doubtless, on a reconsideration of the subject here so ably argued, find ample grounds for the confirmation of his views; whilst to him who may have been in doubt, will be afforded a more satisfactory basis on which to form a decision, than could perhaps be obtained from any exhibition of one side only of the question at issue.

It is not, however, the controversial character of these papers that gives them their great value. It is true that they chiefly relate to the application of lightning conductors to Powder Magazines; but scattered throughout the correspondence, will be found the fullest practical information derived from the highest authorities, upon every point of detail, that will enable any person to understand how to apply *properly constructed* conductors to buildings of every description. The report of a Committee of Officers of the Corps of Royal Engineers, which is added (at page 98) to the Government Correspondence, is also full of important practical suggestions.

In order to make these Selections more valuable and useful, Sir William Harris's well-known work on Thunder-storms has been consulted and freely made use of.

M. Arago's Memoir on Thunder and Lightning (forming part of the volume of his Meteorological Essays, published in 1855, and translated under the superintendence of Colonel Sabine, R. A., Treasurer and V. P. R. S.,) has in like manner been constantly referred to and quoted. In the Introduction to this last-named work, Baron Von Humboldt states that it was revised and enlarged by M. Arago himself during his last illness.

Short extracts from both these works have been given in the form of Notes wherever they could be conveniently applied. A more lengthened extract from M. Arago's Essay, viz., part of the 1st and the whole of the 52nd chapter, which relate to the general utility of lightning conductors, forms an appropriate Introduction; whilst several extracts, of a practical tendency from Sir William Harris's work are added at the end in the shape of an Appendix, which will, it is considered, prove of great use.

W. A. C.

PUBLIC WORKS DEPARTMENT,
January 21*st*, 1857.

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INTRODUCTION.

ON THE GENERAL UTILITY OF LIGHTNING CONDUCTORS.

(From Arago's Meteorological Essays.)

I HAVE often been consulted on the subject of lightning conductors by architects charged with the care of public buildings; by officers of the corps to which rightfully appertains the construction of powder magazines; by the commanders of ships both of war and of commerce; and by a great number of citizens of all classes of society. I may, therefore, be permitted to affirm that, generally speaking, physicists by profession are the only persons who have a true and exact idea of the preserving properties of this kind of apparatus. If lightning conductors are asked for and erected, it is simply out of deference to the decisions of Academies. Every one desires, by this means, to shelter his own responsibility under the Ægis of Science; but as to an entire conviction of the efficaciousness of the method, this, I think, will be rarely found. Some do not go beyond doubts, and wait before pronouncing an opinion until real demonstrations shall be offered to them, instead of mere analogies. Others, comparing the apparent insignificance of the preservative with the vastness of the possible damage which it is designed to avert, declare that it is repugnant to their reason to admit that a slight metallic rod can suffice to shelter a great edifice, or a majestic ship, from the dreaded thunder stroke. In their view, these rods, which shoot up into the air with such high-sounding names and lofty pretensions, are really quite inefficacious either for good or for evil. Others give themselves up to an opposite set of ideas and attribute to these metallic rods a powerful but injurious action. They say that it is deliberately calling down the thunderbolt on the buildings on which such rods are elevated creating a peril which would not otherwise have existed, and endangering, at the same time, adjacent houses, by inviting the descent of the storm-cloud which might else have passed on and discharged its contents harmlessly at a distance.

Frederick the Great of Prussia tacitly ranged himself among those hostile to Franklin's invention when, whilst yielding to public opinion and to that of the Berlin Academy by permitting lightning conductors to be erected on his barracks, arsenals, and powder magazines, he expressly forbid their being placed on the palace of Sans Souci.

It is proved, as matter of fact, that the apparatuses called lightning conductors have preserved the buildings on which they have been established from damage by lightning?

From the manner in which the above question is framed, every one will at once have perceived that the intention in the present chapter is to resolve it exclusively by mere facts, without having in any way recourse to the deductions, highly simple, direct, and legitimate as they are, by which in recent pages the mode of action of the apparatuses in question has been made apparent. The facts we are about to offer will be taken from all countries, and will be numerous, because it is by their number that they acquire value and importance. We do not learn, either from the Bible or from Josephus, that the Temple at Jerusalem was ever struck by lightning during an interval of more than a thousand years from the time of Solomon to the year 70, although from its situation it was completely exposed to the very frequent and violent thunderstorms of Palestine. Remembering the care with which ancient nations recorded strokes of lightning by which any degree of injury was done,—how often, for example, the Roman annals mention the Capitol and other public buildings being struck by lightning,—it appears natural to infer from this silence, with the Orientalist Michaelis, that the Temple did not receive any severe stroke of lightning in the course of ten centuries. The probability of the justness of this inference is much strengthened by the circumstance that the Temple, being overlaid internally and externally with wood, would certainly have caught fire if struck by a violent thunderbolt.

Supposing the fact to be thus well established, we have next, with Michaelis and Lichtenberg, to seek a cause, and we find a very simple one.

By a fortuitous circumstance the Temple was armed with lightning conductors quite similar to those which we now employ, and which we owe to Franklin's discovery.

The roof, constructed in what we now call the Italian manner, and covered with boards of cedar having a thick coating of gold, was garnished from end to end with long, pointed, and gilt iron or steel lances, which Josephus said were intended to prevent birds from resting on the roof and soiling it. The walls also were overlaid throughout their extent with wood thickly gilt; lastly, there were in the Courts of the Temple cisterns into which the rain from the roof was conducted by metallic pipes. We have here both the lightning rods and a supply of means of conduction so abundant, that Lichtenberg is quite right in saying that many of our present apparatuses are far from offering in their construction so satisfactory a combination of circumstances.

The conclusion at which I arrive is, that the long immunity enjoyed by the Temple of Jerusalem presents the most manifest proof of the efficacy of lightning conductors.

In Carinthia, at the castle belonging to the Counts Orsini, the Church, which is situated on a hill, was so often struck by lightning, and so many deplorable accidents had happened in consequence, that at last it was determined not to use it for the celebration of divine service during the summer months. In the course of the year 1730, one single stroke of lightning entirely demolished the steeple. It was rebuilt, and subsequently continued to be struck by lightning four or five times a year on the average, without counting some cases of extraordinarily violent thunderstorms, in which the steeple received five and even ten strokes of lightning in the course of a single day. After one such storm, about the middle of the year

1778, the building was again found so near falling that it was taken down and rebuilt; and this time it was furnished with a pointed lightning rod and a good conductor. Five years afterwards, *i. e.* in 1783, being the date of the note written by Lichtenberg from which I take these details, the steeple, instead of having been struck twenty or twenty-five times, had only been struck once, and even on that one occasion the metallic point had received the stroke, and no harm followed.

In the spring of 1750, lightning fell on the Dutch Clock-tower at New York. It continued its course through several ceilings running down the wire which connected the wheel-work with the hammer which struck the hours. As far as the wire extended, the lightning did no mischief to the building; it did not even enlarge the apertures by which the wire passed through the ceilings, though they were only about half an inch wide. For the greater part of the distance, the wire was only diminished to two-thirds of its previous thickness, but its lower portion was completely fused, and from thence the lightning darted to the hinges of a neighbouring door, broke the door, and then dispersed itself.

In 1753 lightning fell on the same steeple, and produced precisely similar effects, although the wire communicating between the tongue of the bell and the wheel-work of the clock, had been replaced by a small copper chain.

In 1755, a fresh explosion took place; but now the rod of the weather-cock communicated with an uninterrupted external iron conductor, which went down into the moist earth; and this time both the door and the wire of the clock were quite untouched; the building also suffered no injury.

From the time when it was first built, the Church of Saint Michael at Charlestown was visited and injured by lightning every second or third year; at last, a conductor was placed upon it, and in 1774 Mr. Henley was informed from America, that during the course of the fourteen years which had elapsed since the erection of the apparatus, the Church had not been once struck.

In 1772, Toaldo stated that the royal residence at Turin, the Valentino, had ceased to be struck by lightning since Decaria had armed its principal pavilions with slender metallic rods, having attached to their lower extremities wires which went down into the ground. The castle had often sustained injury previously.

The Campanile of Saint Mark's at Venice, of which the construction goes back to a very distant date, is not less than 340 feet high. The pyramidal elevation which rises from it, is 90 feet high. The whole is surmounted by the figure of an angel made of wood covered with copper, and 10 feet high.

The great elevation of this building, its insulated position, and, above all, the multitude of pieces of iron in its construction, render it in a high degree obnoxious to danger from lightning; and, in fact, it has been frequently struck. Unfortunately the town registers do not mention all such strokes; but, generally speaking, only those which entailed large expenses for repairs. The following is the list taken from the documents:—

1388. 7th of June, (no details given).
1417. Pyramid burnt.

1489. 12th of August, Pyramid again reduced to ashes.

1548. June, (no details given).

1565. (No details given).

1653. (No details given).

1745. 23rd of April, great damage done.

Thirty-seven cracks threatened the fall of the Tower. The repairs cost upwards of sixteen thousand pounds.

1761. 23rd of April, damage not considerable.

1762. 23rd of June, considerable damage.

In the beginning of the year 1776, a lightning conductor was placed on the Campanile, and I do not learn that, since that period, the edifice has ever been injured by lightning.

The fine tower of Sienna was frequently struck, and on every occasion much damage was done. In 1777, it was provided with a conductor; and this had but just been effected, when on the 18th of April it received a fresh discharge. But this time no damage was done.

I read in a memoir by Sir William Snow Harris, that six Churches in Devonshire having tall steeples, were all struck by lightning within the short time of a few years; but that one only among them escaped injury, being the only one which was furnished with a lightning conductor.

Geneva is much exposed to thunderstorms, nevertheless the towers of its Cathedral, although the highest edifice in the town, and rising higher than any other object for a great distance in the country around, have for two centuries and a half enjoyed the privilege of not being struck by lightning, while the much lower steeple of Saint Gervais has been repeatedly injured.

Saussure, as early as 1771, sought to discover the cause of this singular anomaly; he found it in the accidental conductors with which the towers of the Cathedral are furnished. The middle Tower is nearly three centuries old; and, said Saussure, "as it is constructed entirely of wood, it must always, as is still the case, have been covered from bottom with tin; now it is easy to conceive that so considerable a mass of metal must always have formed an excellent conductor, and that its widely extended base might easily meet somewhere with some substance to finish the communication." Let us add, in order to complete the explanation of the illustrious Physicist, that the communication with the ground was effected, in different degrees indeed, through the intermediation of all the materials at all parts of the edifice, and that the number supplied what might be wanting in intensity. Lastly, let us remark, that for more than a century the pipes of lea or tin used for conducting the rain-water below ground have constituted a communication more perfect, perhaps, than that of ordinary rods.

The column called "the Monument," in the city of London, was erected in 1677, by Sir Christopher Wren, in commemoration of the great fire of London. Its height is more than 200 feet above the pavement in Fish Street. Its upper portion is terminated by a large metallic basin filled with a number of metallic pieces, more or less contorted and spreading in different directions, and, as they are intended to represent flames, all terminate in very sharp points. Four upright iron bars descend from the basin to the gallery, and support the iron staircase which terminates at the basin. One of these bars, which at its base is fully 5 inches broad and 1 inch thick, communicates with the grappling irons of the stairs which go down into the ground. Every one will see that we have here the multiple points which have been spoken of previously as being used in some lightning apparatuses, combined with good conductors. I am not aware that in the interval which has elapsed since 1677, the Monument has ever been injured by lightning.

The damage done to Strasburg Cathedral by lightning, was formerly almost every year such as to occasion considerable expence. Since the rather recent period at which it has been provided with a lightning conductor, no damage has been sustained, and this item of expenditure has disappeared from the municipal budget.

On the 12th of July 1770, lightning fell at Philadelphia, at one and the same time, on a sloop not provided with a lightning-conductor, on two houses equally undefended, and on a third house which was furnished with such an apparatus. At all these four points the detonation appeared tremendous. The two first-named houses and the sloop were seriously injured; the house which had a lightning-conductor remained perfectly unhurt; only it was remarked that the point of the rod was melted for some way down.

In 1813, in the month of June, at Port Royal in Jamaica, the Ship *Norge* and a merchantman, neither being provided with conductors, were struck by lightning and much injured. The other vessels in the harbour, which were very numerous, and amidst which these two vessels were, sustained no injury: they were all provided with lightning-conductors.

In January, 1814, lightning fell in Plymouth Harbour. Of the numerous vessels stationed there, one only, the *Milford*, was struck and injured. It was the only one which at the moment was unprovided with a conductor.

In January, 1830, in the Channel of Corfu, three terrible strokes of lightning fell on the conductor of the English Ship the *Etna*. The vessel suffered no injury. Two other vessels, the *Madagascar* and the *Mosquito*, which were not far from the *Etna*, were also struck. They had no lightning-conductors, and they sustained considerable damage.

Official Correspondence

ON THE SUBJECT OF ATTACHING

LIGHTNING CONDUCTORS

TO

POWDER MAGAZINES.

No. 1.

To W. B. O'SHAUGHNESSY, ESQ., M. D., *Medical College.*

SIR,

THE Military Board having been called upon* by Goverment to report upon the expediency or otherwise of attaching lightning conductors to powder magazines, I have been instructed to address you on the subject, in the hope that your scientific knowledge may assist the Board in forming a correct opinion on that point.

2. Should the use of lightning conductors be considered by you desirable, the Board would feel obliged by any suggestions that you may be able to offer as to their height, position, size, and number, for any given extent of horizontal or vertical surface.

3. The accompanying Memorandum was received from the Court of Directors, and you are requested to return it with your reply.

I am, Sir,
Your obedient servant,
W. DEBUDE,
Officiating Secretary Military Board.

FORT WILLIAM;
Military Board Office,
22nd December 1838.

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* In consequence of the blowing up of the unprotected Magazine at Dum-Dum.—ED.

MEMORANDUM—*See Diagram.*

The higher a conductor is elevated, the more its efficacy will be increased.*

Therefore, for a powder magazine, the conducting rod, should be elevated seven feet at the least above the highest point of the building; should be placed standing out one foot from the building; † and be made as continuous and direct as possible; branching out at the level of the ground, and carried under ground in a dry brick drain six inches diameter, ten feet long, from thence carried down a hole filled with burnt charcoal, or ashes from the baker's oven.‡

Copper rods, pointed at top with platina,§ are recommended.

As the electric matter from violent storms causes intense heat, it is recommended to have the conducting rods one inch in diameter, which is a quarter of an inch more than they are usually made in England.‖

Strong wood brackets made of teak, or any other hard wood, to keep the conductors firm in their places.

There should be a conducting rod upon the principle here delineated, at each end of the building.

And as the direction of lightning is often determined by that of the rain, the surface on the side of the building might attract it: it would be prudent, therefore, to have a conducting rod on each side of the building as well as at the ends.

The rods should be united with the best screwed joints, with a top screw of the same metal as the conductor.

No. 2.

FROM ASSISTANT SURGEON W. B. O'SHAUGHNESSY, M. D., TO CAPT. H. DEBUDE, *Officiating Secretary Military Board.*

Fort William, December 27th, 1838.

SIR,—I have the honor to acknowledge the receipt on the 24th instant of your letter of the 22nd, on the subject of the attachment of lightning conductors to powder magazines.

2. The question you propose is one of much difficulty. I doubt, indeed, whether the existing state of knowledge regarding the reciprocal

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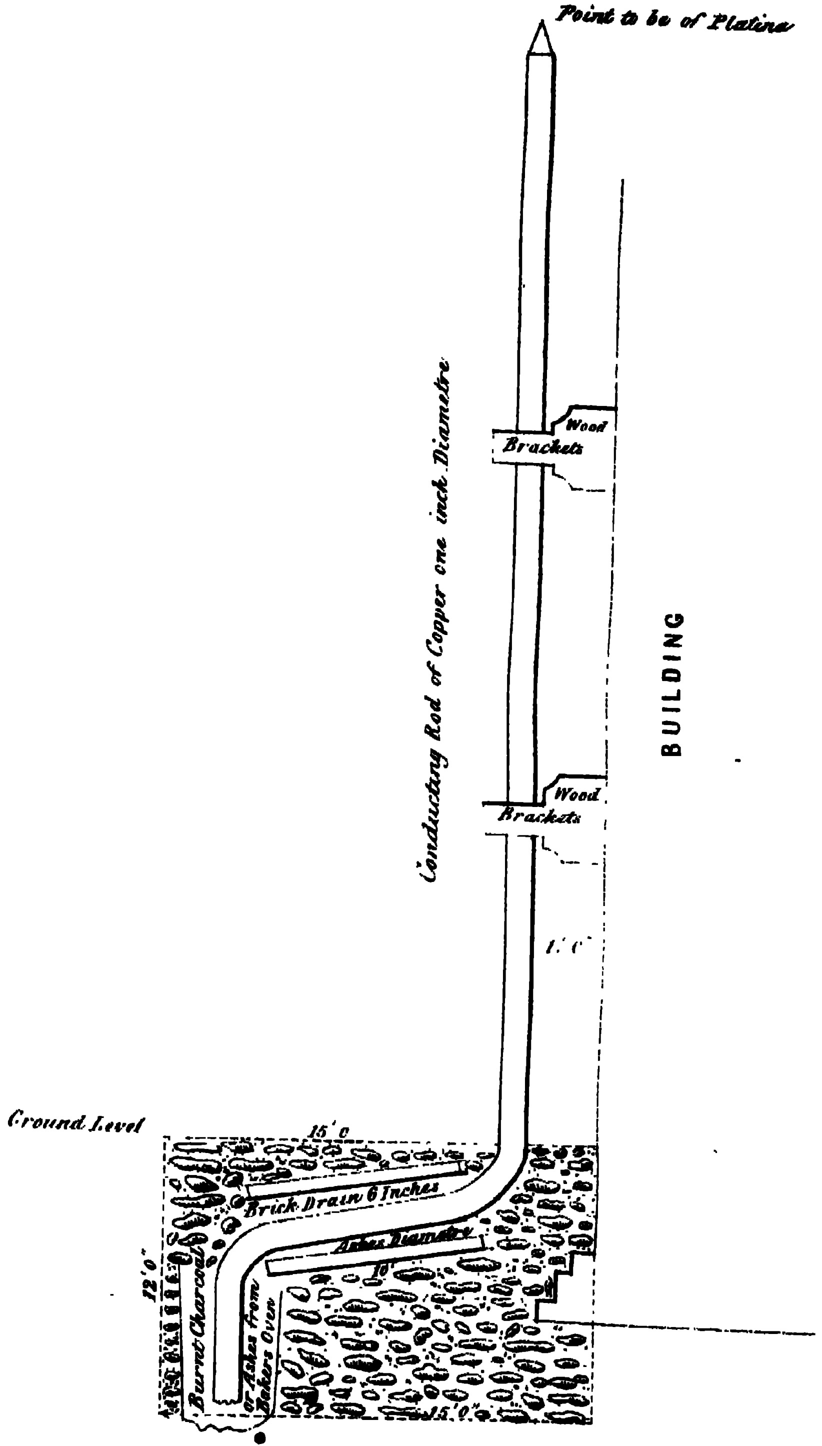
* See Note § page 9.—ED. † See Note † page 9.—ED.

‡ Those constructors of lightning conductors, who are well acquainted with all the resources which science offers, take care to make the conducting bar pass through a kind of well, filled with *bakers braise or embers.* It is indispensable that the charcoal should have been heated to redness; common charcoal cannot answer as well.—*Arago's Meteorological Essays.*—ED.

§ Platinum points are to be preferred to copper ones, not only on account of their inalterability under the action of water, but also on account of their non-fusibility.—*Arago's Meteorological Essays.*—ED.

‖ See Note page 15.—ED.



Lith: at the Surv. Genl's Office Calcutta Feb: 1857.

action of atmospherical and terrestrial electricity, especially during the paroxysms of tropical storms, is as yet sufficiently advanced to warrant the expression of more than a very diffident opinion on its several points.

3. I shall take the liberty of premising some general remarks on lightning conductors, before I take up the special subject of your letter.

4. I am in possession of several facts hitherto unrecorded, which seem to me clearly to show that in ordinary edifices the attachment of lightning conductors, even when properly constructed, is by no means the infallible protection so generally imagined.

5. It is often no doubt easy to explain the occurrence of disasters by lightning to buildings thus apparently protected, on the ground of defective construction of the conductors, or of disproportion between the number of conductors and the extent of area to be guarded. By such considerations we may explain the accident to Government House on the night of the 30th of March 1838, and bearing these in mind, measures may be adopted which in all probability will preserve such edifices from similar visitations.

6. But it is a matter of greater difficulty to explain such circumstances as I am now about to adduce, in illustration of the opinion expressed in paragraph 4.

7. On an evening in May 1837, the house No. 2, in Chowringhee, then occupied by Dr. Goodeve, and next door to the house tenanted by Mr. Trower, was struck by lightning and much damaged.

Dr. Goodeve's house had no conductor, Mr. Trower's had one at the face adjoining Dr. Goodeve's, and only distant therefrom twenty feet.* The conductor is well-constructed.

8. On the evening in question, during a violent storm from the north-west, Dr. Goodeve was walking in the verandah when Mr. Trower's conductor and the corresponding angle of Dr. Goodeve's house were struck by the *same discharge*, and the lightning in Dr. Goodeve's house followed the course of the vertical window bolts represented by the dotted lines in the plan.

9. This case seems to me completely to falsify Biot's opinion, that within sixty feet interval between conductors no accident can occur—and

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* In a subsequent letter Dr. O'Shaughnessy states that this measurement was incorrectly reported by his Native Assistant. It should be 22 yards.—ED.

to show that occasionally, in tropical climates, there is such vast disproportion between the quantity or intensity of the atmospheric electricity and the conducting capacity of protectors, that the excess of the discharge must pass to adjacent bodies.

10. In Chowringhee alone, in an area of one square mile, there are over 300 lightning conductors of proper construction, yet scarcely a season passes but we hear of accidents within that area, and not unfrequently too in houses actually provided with conductors.

11. I attribute these accidents chiefly to the vertical window rods which constitute all over Calcutta, as in Indian houses generally, a multitude of interrupted conductors, the inducing influence of which is sufficient to counteract much of the benefit of the well-constructed rods. These vertical window rods are on a large scale, precisely identical with the models contrived by instrument makers to show at the lecture table the dangers of ill-contrived and ill-applied conductors.

12. 'Were I called on to protect an isolated house of two stories, with angular edges and roof, containing articles of metallic furniture and other good conductors of electricity—under such circumstances I would attach at one angle a common conductor several feet higher than the house, (in order to divert the lightning the house and its contents could scarcely fail, under many circumstances of exposure, to attract,) and at each cardinal point I would place a rod about ten feet high; connected horizontally by thick rods and rivets with the main conductor.

A building so protected I would consider to be as safe, as it is practicable to render it, according to the present state of our knowledge.

13. But in the case of a powder magazine of the ordinary construction, rounded in outline, of trifling elevation, containing no metallic furniture, removed from other buildings, and not necessarily in the contiguity of conducting objects, I think its chances of being struck by lightning are very little more than those of an equal area of soil or terrace.

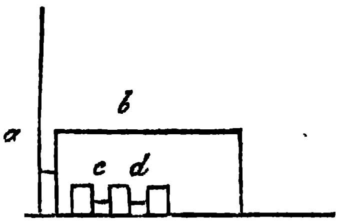
14. We must remember that electric explosions are not chance occurrences,—that they are governed and guided by the influence of "induction," the effects of which are now comparatively well understood; that it is only between objects susceptible of rapid changes in their electric relations that the explosion passes, but that the explosion may exceed

in quantity and in intensity the capabilities* of the dischargers we usually adopt.

15. Another reason for objecting to the employment of conductors in the immediate contiguity of powder magazines is, the danger of their inducing what is called the "lateral discharge," of the nature of which I will venture to offer a few explanatory remarks. *(See Appendix H.)*

16. Suppose a violent discharge to take place along the conductor *a* to the ground; during the passage of the electricity an opposite electric state is induced in contiguous objects, and a spark may pass in the interval between *a* and *b*, and all the articles contained within having their electric state transitorily disturbed, *will give sparks at the same moment*;—if animate, will experience shocks or other effects in proportion to the violence of the primary discharge. Thus the inmates of Dr. Goodeve's house suffered a shock like the discharge of the Leyden bottle at the instant the accident took place described at paragraph 8.

17. Were any peculiarly inflammable matter existing in the interval *a*, *b*, or in the interstices *c*, *d*, the passage of a spark would cause its inflammation, especially if rain were falling at the same time. The explosion of gunpowder by small electric sparks is indeed never certain but when water or moist substances forms part of the electric circuit.



18. I will not enter on any detailed consideration of the dangers connected with what is called the "*return* discharge," in which the electricity is believed to emanate from terrestrial objects and proceed to the atmosphere. Precise facts are wanting to enable us to form exact opinions on this subject.

19. With respect to the materials and dimensions of conducting bars, I think it is altogether unnecessary either to construct them of copper,

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* The opponents of lightning conductors have argued against them from our present ignorance (an ignorance which we must expect will long continue) as to the "maximum" effect which lightning may produce; and therefore, as to the maximum of dimension which "may" be required for conductors. The difficulty, although founded on truth, really has nothing in it which need stop new proceedings.

If we take the dimensions to be given to conductors, from experience; and if that which we adopt has been found to resist the strongest lightning recorded during 3 or 4 centuries, what can reasonably be asked more?—*Arago's Meteorological Essays.*—Ed.

or to make them one inch in diameter. Iron can be preserved bright for an indefinite period by attaching to it small pieces of zinc, on the principle of the galvanic preservation of copper. If its point be gilt or platinized, the rod will, on the contrary, corrode much more rapidly than if entirely unprotected. As to size, I have known very many instances of violent discharges of lightning through window rods, through ill-constructed conductors, over picture frames, railings, through the metallic head of a spear with a wooden shaft, &c. &c. and in no case was complete fusion, or an approach to it, effected, except at the ends where the discharge entered, and from whence it proceeded. The drawing *a* shows the extremities of one of the window rods from Dr. Goodeve's house, and *b* of the spear of the Britannia from Government House Calcutta.

20. As for the silent passage of atmospheric electricity causing the heating of conductors, I scarcely think it possible—certainly no instance of it has been recorded,—and even were it to occur, it could not occasion any mischief.

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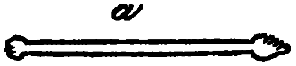

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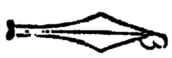

21. To apply the preceding facts to the question before me, I think it inexpedient to attach ordinary conductors, or such as those described in your letter, to powder magazines.

i. Because, being of slight elevation, of rounded surface, and of non-conducting materials, these buildings are scarcely more exposed to lightning than an equal area of ordinary ground.

ii. Because a discharge may occur *too great for the capacity of a single conductor*,* in which case the electricity will divide itself to all adjacent objects.

iii. Because, though the discharge may pass to the ground, the lateral electric disturbance may occasion an explosion within the magazine.

22. But as it may be deemed inexpedient to commit a magazine even to the chances of an equal area of land surface, I think a system of conductors on the following plan would prevent all danger of explosion by direct, or lateral, or even return discharge.

I would erect an iron rod, half an inch in diameter, protected by zinc, at every twenty paces, in a circle drawn round the building, and at least twenty feet distant from it. These rods should be twenty feet higher than the building, be supported by frames of wood or by pillars inserted at their bases as deep as the water level (so easily found in Bengal), and at the surface of the ground they should be connected by horizontal rods secured by riveting. During storms the sentinels on duty should withdraw beyond this line, sheath their bayonets, and pile their arms.

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* See Note page 5.—Ed.

I cannot conceive the possibility of an explosion caused by direct, lateral, or return discharge, taking place within this metallic circle. By such arrangements it is that the electrician discharges through a wire bird cage, without injury to its tenant, batteries sufficiently powerful to destroy a horse, and that he grasps the discharging rod in his naked hand while it is part of a circuit sufficient to cause his instantaneous death.

W. B. O'SHAUGHNESSY.

No. 3.

To W. B. O'Shaughnessy, Esq., M. D., *Medical College.*

Fort William 16*th January* 1839.

Sir,—I am directed by the Military Board to acknowledge the receipt of your letter of the 27th ultimo, on the subject of lightning conductors to powder magazines; and to express the sense which the Board entertains of the care and attention with which the subject has been discussed.

2. As in many instances it would, from the proximity of other buildings, be impracticable to establish a chain of conductors at a distance of twenty paces from a magazine, the Board would be glad to learn whether, in your opinion, a series of conductors at twenty paces distant from each other, but as near the building as ordinary conductors are commonly placed, and secured by wooden brackets, as shown on the Sketch forwarded by the Court of Directors, would add materially to the security of a magazine.

H. DeBUDE,

Officiating Secretary Military Board.

No. 4.

To CAPTAIN DEBUDE, *Officiating Secretary, Military Board.*

January 20th, 1839.

SIR,—In reply to your letter of the 16th instant, I have the honor to state, that under such circumstances as you describe, I would not recommend lightning conductors to be attached to the buildings adjacent to magazines even in the numbers before mentioned, as I feel convinced that placing one or more conductors in the immediate contiguity of the building increases all the dangers attendant on the *lateral* discharge. Indeed I would consider a magazine safer if unprovided with conductors altogether, than with any number placed as you allude to.

I believe we may certainly obviate all danger from *direct* discharge by a multiplicity of connected conductors. I admit too that the *lateral* discharge is not likely to occasion more than a minute spark, such as would not harm a living animal, or injure an edifice, but this spark, however insignificant, can ignite gunpowder, and thus lead to as serious mischief as the direct flash itself.

W. B. O'SHAUGHNESSY.

No. 5.

MR. FARADAY'S LETTER TO MR. SECRETARY MELVILL ON THE PRECEDING PAPERS, WHICH HAD BEEN SUBMITTED TO HIM FOR REPORT BY THE HON'BLE COURT OF DIRECTORS.

Royal Institution, 5th September 1839.

SIR,—I have the honor to acknowledge your letter and the papers, and having read the latter, beg leave to state that my opinion is in favor of lightning conductors. It is no doubt true that low rounded buildings, such as I understand the powder magazines in the East Indies to be, are but very little liable to be struck by lightning, but then if they are struck, the destruction and injury may be very great. It is also, I think, very probable that a lightning conductor may, under *certain circumstances*, cause an electric discharge to take place where none would have occurred no conductor being present, though, on the other hand, there is some evidence to show that conductors cause a diminution in the number of electric discharges to the earth at a given place. It is also very certain that a badly-erected conductor is worse than none and may cause great injury. But notwithstanding these considerations, I have the strongest conviction in my mind that conductors *well applied* are perfect defenders of buildings from harm by lightning. Dr. O'Shaughnessy's papers are very valuable, and serve to confirm my previous impressions; but it would be impossible for me to go over the whole of the opinions and evidence sent me, without at the same time going into a far greater mass dispersed here and there. I would rather refer you at once to M. Arago's popular view of the subject in the Annuaire for 1838, pp. 221, 549, &c., with which I, in almost every point, agree.

I would certainly recommend copper conductors instead of iron, for the former metal conducts electricity almost seven* times better than the latter. When struck, it not only conducts the shock much better, but in the pre-determination of the stroke it determines more of the electricity to itself than otherwise would fall upon it, and therefore tends in any case of a divided shock to leave less to fall elsewhere in its neighbourhood.

I should prefer them pointed. I should not put them far† from the building at their upper extremity, or in their course downwards; but the part that is under ground I should turn from the building in its course through the earth, and take especial care, by plates of copper, to make its contact with the moist earth extensive and good.‡

Conductors should be of a certain height§ in relation to the roof or summit of the building to be defended. A lightning rod rising ten feet above any part of the roof or chimneys of a house, might defend that house perfectly if close to it, but not if ten feet from it; a rod rising fifteen feet above the highest parts of the roof would be more sure than one of ten feet.

A rod projecting ten feet which would protect a building of a certain horizontal extent might protect a building ten feet wide, &c. A lightning rod has been considered as able to protect objects perfectly when they are not more than twice the distance *from it of its height above them:* but for this to hold true, these objects should not be themselves parts of large masses of metal, approaching by their position or connexion to the character of bad lightning conductors.

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* See Note *page* 16.—Ed.

† It should be placed as close as possible to the walls which are to be defended, and not at a distance from them.—*Harris on Thunder Storms, page* 123.—Ed.

‡ See Note *page* 49.—Ed.

§ In extensive ranges of buildings, all the most prominent points should have long pointed rods projecting freely into the air, and the greater the range of building the higher they should be.—*Harris on Thunder Storms, page* 124.—Ed.

I have no fear of lateral discharge,* from a *well-arranged*† conductor. As far as I understand lateral discharge, it is always a discharge from the conductor itself; it might be very serious from a badly arranged conductor, (and in fact makes them worse than nothing,) but with a good lightning rod it can be but small, and then not to badly conducting matter, as wood or stone, but only to neighbouring masses of good conducting matter, as the metals, which either ought not to be there, or if they are necessarily present, ought to be in metallic communication with the lightning conductor itself.‡ I am not aware that lateral discharge can take place *within* a building when a lightning conductor outside is struck, except there be portions of metal as bell wires, or bolts, &c., which may form an interrupted conducting train from the conductor to the interior. It is true that cases which come under the denomination of returning stroke, might perhaps produce a spark in the interior of a building, but the phenomena of a returning stroke cannot occur at the place where the lightning strikes a conductor.

In my opinion, a good conductor well-connected with the earth, cannot do harm to a building under its protection, *i. e.* though it may induce a discharge upon itself, it cannot induce a discharge upon the building, and the discharge in itself cannot give rise to any secondary effects which are likely to place the building in more danger than it would have been subject to, had the conductor not been there.

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* It may be here observed, that if lightning rods are liable to produce lateral explosion upon surrounding bodies, so as to set fire to inflammable matter and cause other destructive effects; then there is not a powder magazine in Europe, armed with such rods, which, upon being struck by lightning would not either be blown up or damaged; but this at least we have shewn has never been the case.—*Harris on Thunder Storms, page* 195.—Ed.

† By a "proper conductor" I mean, on the one hand, that it should go down into the ground until it reaches earth which is always damp; and, on the other, that it should be sufficiently massive to transmit the strongest lightning without being fused by it.—*Arago's Meteorological Essays.*—Ed.

‡ The conductor should involve in its course the principal detached masses of metal in the building.—*Harris on Thunder Storms, page* 123.—Ed.

WM. FARADAY.

No. 6.

REPORT OF PROFESSOR DANIELL TO MR. SECRETARY MELVILL, ON THE SAME PAPERS.

King's College; London, August 24, 1839.

MY DEAR SIR,—I have carefully perused and considered the papers which you have done me the honor to transmit to me, relating to the subject of lightning conductors in the East Indies, and now beg to submit for the consideration of the Chairman of the Court of Directors, according to your request, the following remarks upon them.

2. It is with the greatest surprise,[*] I have learnt that the question of the efficacy of lightning conductors, which has been considered by all the leading philosophers in Europe and America as settled by the uniform experience of nearly one hundred years, is still thought to be undetermined by some of the scientific men in the Honorable Company's Service; and that the Governor General and Council, under the influence of their opinion, have come to the conclusion, that in "attempting to protect powder magazines by their means more danger than advantage is likely to result from the measure." Should this conclusion be unfounded, as I believe all experience will prove it to be, it must be of the utmost consequence that it should be corrected, especially in a country peculiarly liable to the paroxysms of tropical storms. That powder magazines unprovided with conductors are liable to be fired by lightning, is proved by the blowing up of the magazine at Dum-Dum,[†] which gave rise to the correspondence, whereas there is

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[*] It is not easy to explain how, in the present advanced stage of natural knowledge, so many anomalous views and opinions on this interesting subject should pervade the public mind, since in no department of physical science is the field of observation more fertile, or the path of experience more direct and certain.—*Harris on Thunder Storms,* —*Preface, page* xi.—ED.

[†] The building destroyed at Dum-Dum was not a magazine of approved construction, but only an ordinary godown.—ED.

no instance upon record of a magazine properly provided with them, suffering injury from the same cause.

3. In the year 1823 instructions for the erection of lightning conductors were drawn up, at the instance of the Minister of the Interior of France, by a commission of the *Académie Royale des Sciences*, composed of MM. Poisson, Lefevre, Ginian, Gerard, Dulong, Furet, and Gay Lussac and adopted by the *Académie*. The Report is published in the 26th vol. of the *Annales de Chimie et de Physique*.

4. So lately as the year 1837, the facts relating to thunder and lightning again underwent investigation by M. Arago, who has published in the *Annuaire par le Bureau des Longitudes* for 1838 a very detailed scientific notice "*Sur le Tonnerre.*"

5. These two reports have really exhausted the subject, and ought to be sufficient, in my opinion, to convince the most prejudiced; *first*, of the impossibility of any extra danger arising from lightning conductors of proper construction; and *secondly*, of the protection which they are competent to afford.*

6. I have lately had the honor of being appointed by the Government upon a Committee to inquire into the efficacy and best form of lightning conductors for Her Majesty's Navy, and we have just handed in our report to the Admiralty, in which having collected a great body of evidence upon the subject, and having availed ourselves of the opinions of Doctor Faraday and Professor Wheatstone, we have unanimously recommended the general adoption of Harris's conductors on board Her Majesty's ships. The report has been ordered to be printed for the use of Parliament, and I will take the liberty of transmitting you a copy as soon as it is complete. In the mean time, I will endeavour to reply to some of the observations which Professor O'Shaughnessy has made in his report, which is included in the papers referred to me, and upon which, in conjunction with some private observations of Mr. (James) Prinsep, which do not appear, the Governor General's opinion seems to have been formed.

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* With respect to certain prejudiced views and opinions which have been entertained of the operation of lightning rods, we trust to have made it appear, that such opinions are founded on no sound basis whatever; and that a judicious application of pointed conductors, is not only desirable, but is in a great variety of cases quite essential to the preservation of buildings and ships from the ravages of lightning.—*Harris on Thunder Storms, page* 226.—Ed.

7. First, I infer from the general tendency of the observations of these gentlemen, that they entertain the notion that lightning conductors have the power of *attracting* a discharge of lightning to places where without them it would not occur.

8. Nothing can be more unfounded than this supposition.* The intense action which takes place between an electric cloud, of the extent perhaps of many thousands of acres, and an equal area of the earth's surface, is much too extensive to be materially diverted by the mere point† which can be directed upon the latter; and which, as compared with the extent and distance of the charged clouds, must be quite inconsiderable. The path of the discharge which takes place in the form of lightning is determined by what may be the line of least resistance in the whole distance between the two great electrical surfaces, of which the conductor can form but a minute, fractional part.‡

9. Over this fractional part, however, we may have control sufficient for the protection required. It has been well and accurately observed "that lightning conductors can no more be said to *attract* the matter of lightning, than a water-course can be said to attract the water which necessarily flows through it at the time of heavy rain."§ It would be absurd to say that a hollow water-pipe, open at its upper end, and placed perpendicularly, attracts or invites rain from the clouds, or that in providing our houses with such pipes, we incur a greater risk of being

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* Not only is the idea that a lightning rod invites lightning unsupported by any fact, but it is absolutely at variance with the whole course of experience.—*Harris on Thunder Storms, page* 177.—Ed.

† It is quite clear from what has been already shewn, that any artificial elevation on the earth's surface, is in respect of a thunder storm, a mere *point* in one of the terminating planes of a great electrical disturbance, the electrical forces therefore cannot be supposed to operate exclusively between such an elevation and a charged cloud.—*Ibid, page* 72.—Ed.

‡ In all these reasonings we should recollect that the forces in operation are distributed over a great extent of surface, and that the point or points upon which lightning strikes is dependent on some peculiar condition of the intervening air, and the amount of force in operation, not on the mere presence of a metallic body projecting from a comparatively short distance into the atmosphere. "*That such bodies provoke the shaft of heaven is the suggestion of superstition rather than of science.*"—*(Leslie)*—*Harris on Thunder Storms, page* 179.—Ed.

§ The operation of such rods, being purely of a passive kind, can be no more said to invite or draw down lightning upon the buildings to which they are applied, than a rain pipe can be said to draw down or invite the rain which flows through it.—*Harris on Thunder Storms, page* 225.—Ed.

inundated, because they are calculated to discharge freely all the rain which passes into them. No less absurd is it to say that a metallic rod invites lightning, and may be productive of damage, because it is calculated to transmit the electricity which falls on its point.*

10. *Secondly*, Dr. O'Shaughnessy refers to danger which is likely to occur from the erection of conductors in the contiguity of powder magazines from what is called "*lateral discharge.*"

11. There can be no doubt, that a conductor in the moment of a discharge of electricity passing through it, influences in a degree all good conducting substances in its immediate vicinity by induction; but no discharge will take place from it to any neighbouring body, unless it be insufficient itself to conduct the whole of the discharge or unless the body in its vicinity be a better conductor than itself. A lateral discharge, in fact, is only a division of a portion of the principal discharge from an insufficient conductor to another which can relieve it. Now the very purpose of a lightning rod is to provide a sufficient conductor for the electric fluid which may fall upon it, and which will never pass from it, if properly constructed, to any building in its immediate vicinity from the construction of which all metallic substances are, of course, carefully excluded.

12. *Thirdly*, Dr. O'Shaughnessy refers to Dr. Goodeve's house having been struck by lightning, within twenty† feet of a well-constructed conductor upon the house of Mr. Trower, which was struck at the same moment, as falsifying the opinion that within sixty feet interval between conductors no accident can occur; but in another part of his report he attributes this accident, doubtless very correctly, to the vertical window bolts, which he has marked upon his plan, and which constitute a line of interrupted conductors to the ground. There can be no question that the discharge was diverted in this instance; but it does not appear that any damage was done to either house; and if damage did occur to the unprotected house, it would have been doubtless greatly increased by the absence of the conductor upon Mr. Trower's house.

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* A pointed conductor will indeed draw off silently and safely a considerable portion of electricity from a charged cloud, but it can possess no power of determining a disruptive and destructive discharge at a point where it would not otherwise occur.—*Mr. Daniell's Note.*

† See Note *page* 3.—Ed.

It would of course be an act of the greatest folly and ignorance to place a similar line of bolts, ,or any other metallic fastening upon a powder magazine.

13. The case by no means proves, as Dr. O'Shaughnessy seems to think, "that occasionally, in tropical climates, there is such a vast disproportion between the intensity and quantity of the atmospheric electricity, and the conducting capacity of protectors, that the excess of the discharge must pass to adjacent bodies" *unless those adjacent bodies are also of a metallic nature, and themselves good conductors.*

14. Dr. O'Shaughnessy states that "in Chowringhee alone in an area of one square mile, there are over 300 lightning conductors of proper construction, yet scarcely a season passes but we hear of accidents within that area, and not unfrequently too in houses actually provided with conductors themselves."

15. The electrical history of such a district must be extremely interesting, and it would greatly benefit science if authentic facts concerning it were collected and published. It appears that Dr. O'Shaughnessy only mentions the facts upon hearsay, and such evidence is not of weight enough to counterbalance the direct testimony of competent witnesses which abound on the other side of the question. I have no doubt that upon proper inquiry, Dr. O'Shaughnessy would find that the accidents which are said to have occurred in houses actually provided with conductors have arisen from defective construction.

16. It is not supposed that a large number of conductors will avert electrical discharges from a district, though, if properly constructed, they will open safe communication for their passage to the earth.

17. Dr. O'Shaughnessy thinks, that "it is altogether unnecessary either to construct lightning conductors of copper, or to make them one inch in diameter," but in this opinion I have again the misfortune to differ from that gentleman. The best authorities have recommended a rod of an inch* in diameter as the standard size, experience having proved that such a rod has never yet been melted by an atmospheric

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* We may therefore feel quite assured that a copper rod of ¾ of an inch in diameter, or an equal quantity of copper under any other form, would withstand the heating effect of any discharge which has yet come within the experience of mankind.—*Harris on Thunder Storms, page* 115.—Ed.

discharge. It is certainly possible that a rod of less substance might be sufficient to conduct away a flash of lightning, but it is impossible to ascertain the minimum which would suffice, without incurring the risk of failure; and it is a point of very little importance, provided absolute protection be assured.

Moreover a rod of a less diameter would scarcely have sufficient strength to resist the mechanical forces which might be opposed to it.

18. The rod should be of copper,* *first*, because the conducting power of that metal is very much superior to that of iron, being in the proportion of 1,000 to 158. And *secondly*, it is little liable to oxidation and corrosion. I do not think that the application of zinc to iron rods, in the way proposed by Dr. O'Shaughnessy, would be by any means efficient in keeping them bright, at the same time I would rather erect iron conductors than run the risk of a total want of protection.

19. I have no objection to make to the disposition of the conductors proposed by Dr. O'Shaughnessy, but I see no reason for placing them at so great a distance as twenty paces from the magazine. The most material points to be attended to, are their perfect metallic continuity, and their communication with the water of the subsoil. The instructions for the erection of lightning conductors are so minutely detailed in the two reports to which I have already referred, that I think it unnecessary to add any thing more at present, but it will give me the greatest pleasure to afford any further explanations in my power that may be required.

I cannot conclude, without again expressing my strong conviction of the necessity of procuring a revision of the opinion of the Governor in Council upon the subject in question with as little delay as possible.

J. F. DANIELL.

No. 7.

SECOND REPORT FROM DR. O'SHAUGHNESSY TO THE MILITARY BOARD.

To CAPTAIN DEBUDE, *Secretary to the Military Board.*

SIR,—In compliance with your request that I should draw up a further statement of my opinions regarding the attachment of conductors to powder magazines, I have the honor to submit the subjoined observations to the consideration of the Military Board.

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* Taking the conducting power of lead as unity, the following numbers accurately represent the relative value of the other metals available for the purpose of lightning rods: lead 1, tin 2, iron 2.4, zinc 4, copper 12.—*Harris on Thunder Storms, page* 99.—ED.

2. I regret much, that it is impracticable to accord to me the full measure of time desirable for the collection and accurate examination of the numerous facts to which I have obtained a clue, bearing on the question now before us, and many of which corroborate powerfully the views I entertain. I regret this the more, as I have the misfortune to differ in a slight degree with the opinions Mr. Faraday has given, while those which Mr. Daniell somewhat dictatorially professes are widely at variance with mine.

3. I trust I may be pardoned by the Military Board for here publicly placing on record a tribute of my deep respect for Mr. Faraday's labors in electrical science. This department of physics he has made peculiarly his own. My presumption would be measureless were I to depart from the utmost modesty and hesitation, when I venture to persevere in an opinion from which he ever so slightly dissents. I seek however for no more candid a judge than this illustrious philosopher, and on once more referring the subject to his consideration, I will bow to his contrary decision, with the full conviction that I had acted upon, erroneous views.

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5. The question before the Board, is this exclusively—" Are we to attach lightning rods to *powder magazines:* and if so, how are we to place them, so as to ensure the maximum of safety from every accident?" To this question and its bearings, we must limit this discussion. It is altogether a different matter from that with which Mr. Daniell has mixed it up. namely, the attaching of conductors to private dwellings or ordinary buildings. All the circumstances differ so widely, that many of the most important of the facts and arguments which bear on one, are altogether inapplicable to the other.

6. The necessity for attaching lightning rods to powder magazines in tropical regions visited by frequent and violent thunder storms, might at first sight appear so obvious, as to need no further consideration. The document (No. 1) however shows, that of all the magazines in the territories of the Honorable East India Company, (Bengal Presidency) during a period of forty years, only one has been struck by lightning, namely that at Dum-Dum, in the month of June 1836. It will be

seen, as we proceed, that the term "magazine"* was scarcely applicable to the building then destroyed.

7. I stated in my first report on this subject, that I considered a powder magazine, *when properly constructed*, arched and rounded in its outlines, of low elevation, and free from metallic masses in its walls and roof, to be as little exposed to accident as an equal area of soil or terrace, the chances of which being struck by lightning are so infinitely small as scarcely to deserve serious consideration. The Dum-Dum explosion took place in a common building of square form, formerly a godown. It was not a magazine, but a mere store-room for the powder used for the laboratory. It stood in the corner of a yard crowded with guns, gun-carriages, heavy metal tools, shells, and other powerful conductors of electricity. It was exactly what it ought not to have been, and the explosion which occurred, by no means invalidates the position, that the well-constructed magazine has but an infinitely small chance of being struck by lightning.

8. The questions now arise—*first*, would even this minute contingency be obviated thoroughly by a lightning conductor being attached to the magazine, on the method advised by the Honorable the Court of Directors? *secondly*, can the conductor itself by possibility become a source of collateral danger?

9. I will take up each of these questions in detail. I grant in the first place, as the foundation of the argument, that metallic conductors have the power, when properly placed, of SILENTLY† drawing off *considerable* accumulations of electricity from the clouds; and, *secondly*, of guiding away to the earth *considerable* direct *explosive* discharges or *flashes of lightning*, without permitting the electric matter, whatever it be, to impinge *directly* on any adjacent bodies.

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* See Note, *page* 11.—ED.

† Thus the lightning conductors, which we now place on buildings, as protections to those buildings against damage by lightning, have, in addition to their value in this respect, the property of gradually depriving the storm clouds of the fulminating matter with which they are charged, and which the conductors carry off and convey silently and harmlessly to the ground. If we suppose the fulminating matter accumulated in the clouds not to be susceptible of sudden reproduction, it will follow that lightning conductors must have an effect in diminishing the intensity of thunder storms, and the number, violence and severity of strokes of lightning.—*Arago's Meteorological Essays.*—ED.

10. The extent to which the protecting influence of a conductor extends laterally, has long been a subject of attention and discussion. Leroy, in 1783, asserted that a rod four to five metres high, above the roof of an ordinary building, defended a circle of sixteen metres radius, or more than three times its own elevation. *(See Appendix, Note F.)*

11. The Academy of Sciences in 1823, in a report to the Minister of War, adopted the opinion of M. Charles, that the circle protected was of a radius double the total elevation of the conductor *above the roof.* This opinion seems to have been generally adopted, but must be modified in consideration of the facts which M. Arago has collected, and some of which have come under my own observation.

12. If masses of metal of any kind enter into the construction of a building, the protecting influence does not extend to the distance above mentioned. The powder magazine of Purfleet, provided with a conductor erected by Franklin and Cavendish, was struck by lightning twenty-four feet from the nearest part of the conductor, which was twenty-six feet* above the roof —the distance being less than the simple height. The parts struck contained a metallic cramp..

13. Dr. Winthorp of New Cambridge reports, that a tree was struck by lightning when but fifty feet from a conductor attached to the steeple of a church, which may reasonably be supposed to have been at least fifty feet higher than the tree.†

14. All that we are entitled to infer from the facts before us, is— that in order to give safety from direct and *ordinary* discharges, we must erect so many conductors, that no point of the roof shall be further from the conductor than twice the length of the height of the conductor above the level of the roofs ;‡ and this applies only to flashes from clouds

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* Twenty-six feet above the level of the slabs of the cornice, and 11 feet above the point of the roof, according to Arago's account.—Ed.

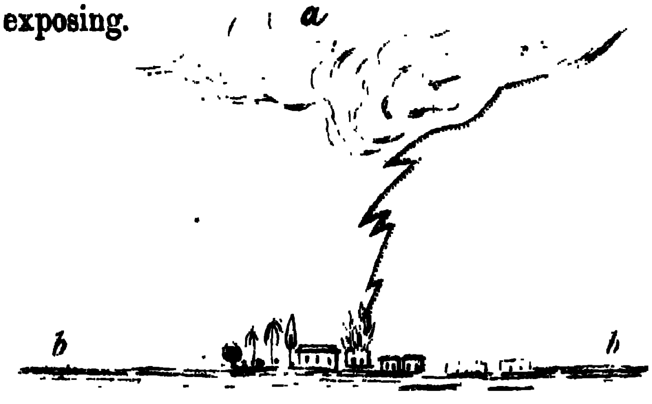
† M. Arago's deduction from this accident is as follows :—If, as seems natural to suppose, the height of the steeple, was not less than six-and-twenty feet above the top of the tree, the fact related by Dr. Winthorp would be directly at variance with the idea, that the radius of the action of a lightning conductor is to be measured by double the absolute vertical height of the extremity of the rod above the objects to be protected.--*See Arago's Meteorological Essays.*—Ed.

‡ Taken conjointly, the above facts authorise the assumption, that the preserving action of lightning conductors erected on the tops of buildings may be safely estimated to extend to a horizontal distance, equal to twice the height of the rods of the conductors measured from the points on which they are fixed.—*Ibid.*—Ed.

in a *calm* atmosphere, and *above* the building. The area of protection is unquestionably much contracted, under the circumstances, so common in India, of a thunder cloud being blown with hurricane velocity across a plain, before a furious squall. Nothing but a line or chain of conductors connected together by horizontal metal bars, and surrounding a building, can possibly protect it from discharge under these paroxysmal storms. This is the opinion I offered in my first report, dated the 27th December 1838; and I have now but to repeat, that one or even two conductors are not an adequate protection, and to *ensure* safety, several must be erected. The subsequent considerations will probably bear me out in stating, that a properly built magazine, with but one, or any inadequate number of conductors, is in greater danger of explosion, than if it had none; and that with ever so many conductors, these should be placed at a considerable distance* from its walls.

15. I proceed now in the attempt to sustain my opinion, that "a magazine with but one, or any inadequate number of conductors, is in greater danger than if it had none."

16. The cause of a lightning discharge selecting the conductor is to be traced in the law of electrical induction, which I hope to be pardoned by exposing.



Nature of the Flash

The cloud *a*, highly charged with electricity of either kind (let us say, *positive*,) approaches the earth, and by the approximation causes the natural electricities of the earth *b* to separate, and that of the *negative* kind to accumulate at the surface opposite to the cloud. The intervening particles of air are thrown into a polar state. The cloud is attracted by the earth, the electricity of which becomes most accumulated on the buildings and objects on its surface, in proportion to their degree of conducting power. At length the resistance to the rushing together of the two opposite electricities is overcome, and a discharge by explosion takes place, the best conductor on the earth receiving all the electric discharge *it is capable of conducting in the time* the discharge occupies. Of all such bodies a pointed metallic rod is the most likely to receive a discharge, and will lead off the greatest quantity thereof to the earth.

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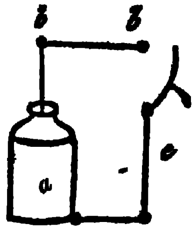
* If the conductor be placed at a short distance from the building, it is decidedly badly placed, since experience has shewn that discharges of lightning are often uncertain, and determined through the air in other directions than that of the conductor. Hence we cannot apply a conductor too close to the walls of a building which we desire to defend.—*Harris on Thunder Storms.*—ED.

17. Mr. Daniell has indeed stated, that a pointed bar must cause a silent discharge without explosion.* I am unable to comprehend how Mr. Daniell could have fallen into such a misconception. The whole history of lightning accidents, teems with instances of well constructed *pointed* rods having been struck, and the points melted. Look at the accident to Mr. Trower's house for example.† The conductor is faultless in its construction, and the *flash was seen to strike it* by Dr. Goodeve.



But let Mr. Daniell try this simple experiment. Let *a* be a Leyden jar, *b* a rod and ball connected with the inner coating, *c c* a rod and ball connected with the outer coating, *b* represents the excited cloud, *c c* the excited surface of the earth. To the ball of *c* apply one branch of a *pointed* discharging rod, and then RAPIDLY *approach* the other *point* to the ball *b*. A hiss is heard for an instant and a loud explosion then ensues. If the point had been brought *very slowly* towards the ball *b*, there would have been nothing more than a silent, or at most a hissing, discharge. Mr. Daniell will perhaps admit that it is the same thing, that the earth carrying the conductor should approach to the cloud, or the cloud approach to the earth; and he will see in this experiment that it is simply the degree of velocity of the approach that governs the nature of the discharge. The electric cloud in a calm atmosphere will give off a constant and quiet stream to the rod—but let the cloud be driven onwards before the wind, or drawn within the vortex of mechanical electrical attraction, and then EXPLOSION *will inevitably ensue.*

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* "*A pointed* conductor will indeed draw off silently and safely, a considerable portion of electricity from a charged cloud, but it can possess no power of determining a disruptive and destructive discharge, at a point where it would not otherwise occur."—*Mr. Daniell's Paper, para. 9.—Note by Dr. O'S.*

† Described in Dr. O'Shaughnessy's first Report.—ED.

18. So much for the cause and nature of the direct lightning flash *to a single pointed conductor*. Let me beg the Board to honour me with their attention to this distinction, as it is essential that no misconception should arise.

19. An *explosion* then, it must be admitted, may occur to a *pointed* conductor. I have next to show that this explosion, or the flash, or the quantity of the electricity passing (which I use as convertible terms) may be so much greater in quantity than the single conductor can convey *in the time* of the discharge, that a considerable part, nay, the whole of the excess, must pass to the adjacent objects. To make my meaning clearer; —Let us suppose the cloud to be charged with 1000 parts of active electric matter—let us *assume* the conducting power of a lightning rod to be equal to 250 *in a unit of time;* I believe that the 750 parts in excess, will, *in the same unit* or instant, pass off in *every direction* to surrounding objects, striking those which offer it the best conducting path.*

20. In proof of this assertion, I refer to the accident to Dr. Goodeve's house, which I have already reported. Dr. Goodeve's house is twenty feet from Mr. Trower's. Dr. Goodeve while walking in his verandah *saw* the lightning strike Mr. Trower's conductor, and at the same time strike his own house; taking, as might be anticipated, the window bolts, and other metallic bars in its course.

21. Let me cite another and a most important fact from M. Arago's rich collection. The house of Mr. Raven, in Carolina, was provided with a conductor formed of an iron bar fixed in the roof—a brass wire outside the wall thence led to another metal bar planted in the earth. The conductor was struck by lightning; the wire was melted as far as the ground

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* The opponents of lightning conductors have argued against them from our present ignorance, (an ignorance which we must expect will long continue), as to the *maximum* effect which lightning may produce; and therefore, as to the maximum of dimension which may be required for the conductors. The difficulty although founded on truth, really has in it nothing which need stop our proceedings. If we take the dimension to be given to conductors from experience, and if that which we adopt has been found to resist the strongest lightning recorded during three or four centuries, what can be reasonably asked more.—*Arago's Meteorological Essays.*—ED.

floor—the lightning then pierced the masonry of the wall at a right angle, exactly where a gun was standing against the wall in the kitchen, the barrel was struck but uninjured, the stock broken, and thence the electric matter passed to the ground.

22. Here we have clearly lateral deviation from a conductor, *and the excess passing to the nearest conducting object.* The wire, was disproportionately small for the quantity of the discharge, it was fused, and the excess passed to the adjacent conductor. It will be objected, that this would not have happened, had the lightning rod, or wire, been of the ordinary dimensions, that the conductor could not have been fused, and the lightning could not have left it. In reply, I point once more to Dr. Goodeve's house. Mr. Trower's conductor was not melted, and yet Dr. Goodeve's house was simultaneously struck.

23. Look to another fact, cited by Arago. A French vessel of war, *La Junon*, was running before a brisk gale. A copper conductor of twisted wires led from the main-mast head to windward, and was secured by copper strips to the ship's side. A flash strikes the top, and a flash is seen by all on board, at the same instant to leave the conductor about on a level with the cap of the main-mast and to dart into the water over the *lee* bulwarks. This is a clear instance of an excess of electricity leaving a conductor through which it cannot force an instantaneous passage. All that the conductor could convey was borne off to windward—the rest opened to itself another and less difficult passage.

24. It might here be the most appropriate place to discuss the question, What is the greatest mass of metal a flash of lightning can fuse? When we remember that the surface of a cylinder increases by a simple multiple of the diameter, while the mass increases as the cube —that every fact shows it to be the *surface* which the electricity pursues,[*] while its calorific effect must be in the inverse proportion to the

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[*] Mr. Harris, a high authority on electricity, makes these remarks respecting the surface action of conductors :—

"The conducting power of a metallic rod has but little relation to its solid contents but is principally dependent on its surface, from which cause the mere gilding of a ball of wood is found to conduct a proportionate electrical discharge with the same facility as if the ball was a solid mass of metal, hence a less quantity of metal formed into a hollow tube would be as a conductor, even more effectual than a solid rod of the same diameter

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mass—it will probably seem that the surface may be inadequate to convey a quantity of electricity, although this be insufficient to melt or even to heat the *whole mass* of the metal. *(See Appendix, Note E.)*

25. Mr. Daniell, in reference to the efficacy of single conductors, enters on the much vexed question as to whether they *attract* lightning, or are merely passive conductors for its conveyance. He takes the latter view, declares the former to be *absurd*,* and compares the conductor to a water-course, a favorite illustration† of his as it occurs in more than one part of his published writings. Practically, it is but of little consequence whether the conductor be active or passive; but of all the substances excited at the moment—engaged in the vast induction we have described—of the cloud, the air, the earth, and the things on its surface—the lightning rod is that in which the induction is the most powerful and towards which the explosion is therefore the most likely to occur. Call it passive, if Mr. Daniell so pleases, but the electric fluid is more active in it than any where else. The discharge takes place; the first instalment, or the head of the column rushing to the point of the conductor, heats the air through which it passes, rarifies it and diminishes the resistance to the outpouring of the rest of the electric accumulation. The excess, unable *in a unit of time* to pass over the bar, rushes to surrounding objects.‡ Did it occur to Mr.

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because its superfices would be increased !"—*Harris on Electrical Conductors, p.* 31.—*Note by Dr. O'S.*

In Appendix, Note E, will be found a more clear explanation by Mr. Harris of the distinction that he makes between solid content and surface.—Ed.

* The Board are referred to the marginal note at para. 17, for Mr. Daniell's own admission, that pointed conductors "draw off" a considerable portion of electricity, &c. &c *Drawing off* and "*attracting*" are very like synonymous terms.—*Note by Dr. O'S.*

We have however already shown, that pointed metallic rods, have no such attractive influence, and that discharges of lightning are determined towards the earth by very different causes But even if it were true that a pointed metallic rod did invite or attract lightning towards it, still we cannot suppose it to attract more than it can conduct since the attraction would entirely depend on the superior conducting power of metals; to assert, therefore, that a conductor can draw towards it, more lightning than it can conduct, is to assert in other words that it attracts more than it can attract, which is evidently an absurd proposition.—*Harris on Thunder Storms, page* 222.—Ed.

† In this instance the illustration is quoted from Sir W. Snow Harris.—Ed.

‡ The Board are requested to consider *Mr. Faraday's* opinion on this point.—

" The fact however is, that disruptive discharge is favorable to itself. It is at the outset a case of tottering equilibrium, and if time be an element in the discharge, in however minute a proportion, then *the commencement of the act at any point favors its continuance and*

Daniell that no prudent man builds his house by preference on the bank of a mountain water-course? The water-course is doubtless *passive*, and it will quietly and silently carry off the stream of an ordinary shower; but the rains may sometimes fall in excess, the stream swell to a torrent. As the waters require *a given time* for the flow of a certain quantity, the excess inundates the bank, and the house is overwhelmed. The parallel seems to me to be complete, although Mr. Daniell's ingenuity may probably succeed in placing the question in a different, and less intelligible light.

26. With very great respect for Mr. Daniell's acquirements, I cannot help wishing he had the opportunity of increasing his practical knowledge, by observing a tropical storm. Had he seen the whole horizon one dense mass of electric clouds—had he heard crash after crash, a hundred times repeated, like the broadside of a line-of-battle ship—had he seen the lightning strike (as I have) three times within a few seconds, and not a hundred feet from my house—had he been in a storm in which thirty-one persons perished,—he would very probably participate in my idea, that electrical accumulation very commonly surpasses the conveying power of ordinary conductors; and the consequence might be as apparent to his mind as to mine, that the excess must pass to the most adjacent objects.

27. These facts appear to me sufficient to warrant my opinion, that there is more danger in giving one conductor to a magazine than in leaving it unprovided altogether. It appears to me, further, as I have already stated, that even from any number of conductors there is another

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and INCREASE, and portions of power will be discharged *by a course which otherwise they would not have taken.*

"The *true heating and expansion of the air itself by the first portion of electricity which passes must have a great influence in producing this result.*

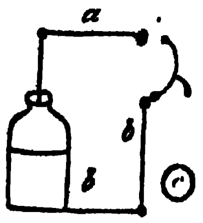
"As to the result itself, we see its effect in every electric spark, for it is not the whole quantity which passes that determines the discharge, but merely that small portion of force which brings the deciding molecule up to its maximum tension; then when its forces are subverted, and discharge begins, *all the rest passes by the same course* from the influence of the favoring circumstances just referred to, and whether it be the electricity on a square inch or a thousand square inches of charged glass, the discharge is complete. Hereafter we shall find the influences of this effect in the formation of brushes, or it is not impossible that we may trace it producing the jagged spark, and forked lightning."—*Faraday's Experimental Researches*, paras. 450, 451, and 1417, 18, 19, 20.—*Note by Dr. O'S.*

source of danger in what I term the *lateral discharge*,* unless the conductors be placed at a considerable distance from the magazine. *(See Appendix, Note H.)*

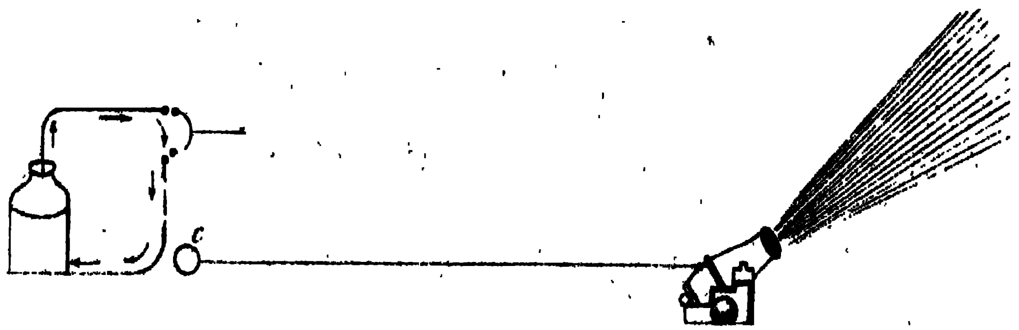
28. As much controversy has arisen regarding this lateral discharge, I wish to explain clearly the meaning I attach to the term. If this be patiently considered, I think it will be found that it is more about the fitness of words than the nature of the facts, that the difference of opinion exists.

29. I select an experiment with the Leyden bottle to exemplify my statement.

Let *a*, be a ball and wire connected with the inner coating, *b b* with the outer coating of a charged bottle—let *c* be a metallic ball placed near, but not touching the rod *b*; when the discharge is made by bringing *a* and *b* into contact, by means of the moveable rod *d*, as the electricity passes through the rod *b* a spark takes place between it and the ball *c*, although the ball *c* is out of the direct circuit.



30. This spark all electricians have seen; its existence *is universally admitted*. The ball *c* may be connected with the ground, or with a long wire, and the spark will still pass. If the ball be connected with a wire, and the opposite end of the wire with the apparatus called "Volta's cannon," charged with inflammable air, *at the* INSTANT of connecting the outer and inner coatings or discharging the jar, the cannon is exploded also, thus:—



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* It may be here observed, that if lightning rods are liable to produce lateral explosions upon surrounding bodies, so as to set fire to inflammable matter, and cause other destructive effects; then there is not a powder magazine in Europe, armed with such rods, which upon being struck by lightning, would not either be blown up or damaged; but this at least we have shewn has never been the case.—*Harris on Thunder Storms.*—Ed.

Gunpowder, spirits, and other inflammable matters may be fired by this spark, although it is manifestly far *out* of the *course of the* MAIN *discharge*, (shown by the arrows in the figure.)

31. There have been several attempts to explain the occurrence of this spark. The older electricians, and Henry of New York, regard it as the effect of induction in the bodies adjacent to the main conductor; that it is not a direct emanation of electricity from the conductor to the lateral objects. Mr. Daniell says it is only the EXCESS from *an insufficient conductor* which passes to the adjacent object. This idea any one possessed of a Leyden jar and a few pieces of wire may set aside by a simple experiment, when he will find the success of each attempt at obtaining the lateral spark increased by increasing the mass of the prime conductor. Mr. Faraday however supposes this extra spark to be a direct expansion of the electricity—that with a good lightning rod it can be but small, and then not to badly conducting matter, as wood or stone, but only to neighbouring masses of good conducting matter, as the metals,* which either ought not to be there, or if there, be in metallic connexion with the conductor.

32. On this I will only observe that the spark now alluded to, whatever be its cause or nature, may be expected to increase in power in direct proportion to the quantity of electricity in the original flash. If with a quart Leyden jar we can procure, as I have repeatedly done, a secondary or lateral spark half an inch long, capable of inflaming gases and gunpowder, I think I am not straining the inference too far, when I believe that the discharge of 10,000 acres of excited cloud may cause a secondary spark or flash capable of passing through the wall of a magazine and exploding its contents. The magazine, moreover, contains powder barrels lined with copper, and even though no flash or spark pass *through* the wall, the barrels themselves may give sparks to each other under the influence of the electricity passing *outside*. Mr. Faraday has shown in one of the most perfect of all his matchless researches, that without the

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* Mr. Harris has, indeed, recently asserted that increasing the primary does not increase the secondary one; but I must state, with every respect to this gentleman, that I have repeatedly exhibited to my classes, long before his paper was published, the experiment described at para. 30—and that I have often shown, that while success is uncertain with a small jar, it is infallible with a large one. I had not the means of measuring the spark, but its increase was plainly visible and palpable, as we increased the battery and its charge.—*Note by Dr. O'S.*

direct conveyance of electricity, the *walls* of an apartment in which a common electrifying machine is worked, are in a state of active electrical excitement.

33. Mr. Harris, who is doubtless a highly accomplished electrician, has recently published some views regarding this spark, which require a cursory notice. Mr. Harris, when ten years ago he proposed his system of ship conductors, was either unaware of the occurrence of this spark, or held it in such little respect that he actually led one of his conductors *through* the after powder magazine, and he has recently induced the Lords of the Admiralty to order this system to be adopted through the Navy.

34. Mr. Harris admits the *existence* of the lateral spark, but attributes it to what is commonly called the "residual charge." Thus after discharging a battery, it is well known that a small secondary charge collects, and will give a spark or shock to any conductor touching both the coatings.

35. I repeat, that it is but little consequence what the *cause* or *nature* of the spark in question be. It is its *existence only* that should influence this question. But if Mr. Harris will repeat the experiment described at para. 30, he will find the explosion of the cannon to occur *at the very same instant of time* as the discharge of the jar, and that *after this,* he will still succeed in obtaining the residual discharge on contact of the inner and outer coatings.

36. The accident which befel Her Majesty's Ship *Rodney*[*] last year in the Mediterranean, shows the occurrence of the lateral, or extra discharge in a form which scarcely admits of mistake; the flash struck the main-top-gallant mast, and escaped from the mast seven feet above the deck, and was seen by all on deck to go over the lee-nettings, and strike the sea a short distance from the ship. *Sparks were seen by many of the officers between-decks,* and many of the men declared they saw balls of fire on the lower deck, and ran after them to throw them out[†]

Here is another instance of lateral or indirect effect. At the moment Dr. Goodeve's house was struck, Mr. Hutchins, sitting in a room on the ground floor several feet from the course of the lightning, received a severe shock. Whatever produces a shock will in greater quantity cause a spark, and if the spark be but the tenth of an inch in length, it can inflame powder, which is the great matter we have to guard against.

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[*] Neither in this nor in Mr. Harris's account of the accident is mention made of any conductor being attached to the mast.—Ed.

[†] See Sturgeon's Annals of Electricity, October 1839, page 166.

37. In connexion with this subject M. Arago gives us some very useful hints. A few detached sentences may be quoted to show M. Arago's ideas :—" Lightning once engaged in a metallic bar of sufficient dimensions, and well constructed, will not quit it to strike the materials of which buildings are usually constructed, but in SUCH SMALL QUANTITY that *no injury can arise*, nor even any appreciable effect."

38. M. Arago is here writing of ordinary buildings. But what would produce no appreciable effect on these, would cause the explosion of a magazine.

39. M. Arago proceeds to ask, "should conductors be placed within or external to, buildings?" The Board will see how this bears on Mr. Harris's ship conductors, which *run* THROUGH *the after magazine.* "I confess," says M. Arago, "that on this point I would be much less affirmative. Voltaire used to say, " there are some great lords not to be approached without extreme precaution, and lightning is one of them.' I think the illustrious author is perfectly right, especially when I recollect the case of Mr. Raven's house, already alluded to. Doubtless the conductor was not sufficiently thick; but here is an occurrence in which all was apparently in good order, the conductors acting as well as could be desired, and nevertheless there was a deviation of the electric matter."

* * * * * * * *

" The 31st July 1829, in the Jail of Charleston, at the moment of an immense thunder clap, 300 persons received a violent shock, the effects of which lasted for some seconds. * * * * *

" The jail had three good conductors, eighteen feet apart: the building was untouched by the lightning." * * * *(See the Annuaire for* 1838).

40. How did the inmates receive this shock? M. Arago refers it to the large quantity of iron the building contained. Can I be accused of exaggeration, when I express my belief, that the same cause, which independently of direct discharge occasioned the shocks here alluded to, might in a magazine of powder barrels be sufficient to occasion minute sparks, and the consequences to which these will naturally lead?

41. Lastly, M. Arago alludes to the proposition of Toaldo, sanctioned by the Academy of Science, that for powder magazines, the conductor

should be placed at two or three metres from the walls, on vertical masts. He approves of the idea in principle, but describes its practical application as too expensive, owing to the number of conductors which would be required.

42. But there is one most important experiment by Professor Henry, of New York, to which I earnestly invite the attention of the Board. I wish my humble voice could reach the Lords of the Admiralty with effect, and that by an appeal to the good sense of men, who have only public interests at heart, and who have no previous scientific doctrines to combat for, that I could induce them to pause before they provide the British Navy with the dangerous conductors Mr. Harris has led them to adopt.* Professor Henry led a copper wire, forty feet long, from the prime conductor of an electrifying machine, into a deep well, full of water. On working the machine, from every part of this wire large sparks were obtained, and a voltaic cannon was fired by one of these sparks close to the surface of the water. Nay more, Professor Henry repeated this experiment on a lightning conductor attached to his house, and properly constructed in every way. From every part of the conductor sparks were given off.

43. But even in the paper by Mr. Faraday, I find ample admission of many of the facts I have contended for. "It is no doubt true, that low rounded buildings, such as I understand powder magazines to be in India, are but little liable to be struck by lightning." "It is also, I think, very probable that a lightning conductor may, under certain circumstances, cause an electric discharge to take place, where none would have occurred, no conductor being present."

44. Let us hear what Mr. Daniell himself is candid enough to allow. *(See para.* 11 *of his Report.)*

"There can be no doubt that a conductor in the moment of a discharge of electricity passing through it, influences in a degree all good conducting substances in its immediate vicinity, by induction, but no discharge will take place from it to any neighbouring body, *unless it be* INSUFFICIENT ITSELF to conduct the whole of the charge." * * *

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* It is not unimportant to observe, that since the year 1829 above 30 of Her Majesty's ships have had pointed conductors fixed in all their masts. These vessels have been at sea, and exposed to severe thunder storms in all parts of the world; and although, as we have just shewn. heavy electrical discharges have fallen upon them, yet in no instance has any damage or inconvenience been experienced; on the other hand, about 41 vessels not fitted with fixed conductors (more than ¼ of the average number of ships at sea, or on foreign stations) are known to have been struck and damaged during this period (ending 1842).—*Harris on Thunder Storms, page* 174.—Ed.

45. To this I have only to add, that since my first Report (Dec. 1838), in a paper published by Mr. Sturgeon in the Annals of Electricity for October 1839, precisely the same ideas as those I entertain are fully and ably advanced. Mr. Martyn Roberts, a well known Electrician, advocates the same views—such also were the opinions of my admired and esteemed friend James Prinsep, whose name alone is full proof, to the Indian community at least, of the sterling value of the conclusions he arrived at.

46. From the consideration of all these facts and reasons, I think myself justified fully in adhering to the opinions expressed in my first report. I do not, and never did, deny the protecting power of well-constructed conductors erected in a given number. I stated distinctly all the circumstances from which danger might result, and how I conceived these might best be avoided. I freely admit copper to be superior to iron, but I wished to avoid expense in introducing the system I proposed. On that system I conceive all danger would be obviated, while in the method proposed in the letter from the Honorable Court at least two highly probable causes of accident remain in full operation.

47. Having obtained through your Board the sanction of Government to the publication of the papers by Messrs. Faraday and Daniell, I will take care that the views therein contained shall be generally made known. In an early number of the Journal of the Asiatic Society, I propose further to print an abstract translation of M. Arago's remarkable Essay "*Surle Tonnerre*" which I saw for the first time when it was sent to your Board, along with Messrs. Faraday and Daniell's papers. The interesting facts with which M. Arago's memoir abounds, will doubtless lead many competent observers to study the phenomena and effects of lightning on the grand scale in which these may be witnessed in India. A multitude of facts will doubtless be thus quickly accumulated, and from these we may reasonably hope to found certain opinions on the points still open to doubt and discussion.

48. The electrical history of Chowringhee I will take care to collect for Mr. Daniell's gratification, with the precision he is good enough to recommend me to observe. I only regret that this is not the appropriate place for noticing the very courteous remark he has made upon this topic.

49. I designedly forbear from all observations on the attachment of conductors to *ordinary* edifices, whether private or public. No one is more convinced of their value than I am, but I am at the same time as satisfied that as they are usually constructed they are sources rather of danger than of protection; referring therefore, with great respect, to my first report, I can only modify the suggestions therein given to the extent, that I believe six to ten feet interval between the walls of the magazine and the conductor will suffice, instead of the more considerable space, 20 feet, which I first recommended. With this sole exception, I am deeply impressed with the belief that it were wiser to commit our magazines to the same chances through which they have passed unharmed for the last half century, than expose them to the possible dangers I have described to proceed from the attachment, in the ordinary manner, of an inadequate number of conductors erected at but one foot from their walls.

50. To economize materials, it would be advisable to erect a wall as high as the roof of the magazine, ten feet distant from it all round. At each corner of this wall a conductor twenty feet higher than the roof and properly led to the ground as deep as the water level, should be placed. Between these conductors, at every ten or fifteen feet, I would place a pointed bar six feet long, inclining outward at an angle of 45°; all these bars should be connected at their bases with the corner conductors by a broad strip of sheet copper led along the wall.

W. B. O'SHAUGHNESSY, M. D.

Medical College, 24th June 1840.

No. 8.

LETTER FROM DR. O'SHAUGHNESSY, SUPPLEMENTARY TO HIS SECOND REPORT,

To MAJOR DEBUDE, *Secretary to the Military Board.*

Calcutta the 30th December 1840,

SIR,—I HAVE the honor to return herewith the plans of magazines and the descriptions of adjacent objects received with your letter of the 1st instant. I have drawn up memoranda upon each, in which I state fully the number and position of the condutors which I recommend.

Attentive consideration of the specifications you have sent me has led me to believe that a much cheaper and more efficient system of conductors is applicable in many cases than that which I proposed in my previous papers, before I had received from you the data your last despatch supplies.

I would, in the first place, remind your Board that every fact in the history of lightning shows it to be *surface* of conductor, not *mass*, which is required for the safe conveyance of the electric discharge.

Secondly.—That copper is unequivocally shown and admitted by all authorities to be about seven times superior to iron in conducting power.

Thirdly.—The cost of inch copper bars being at least Rupees 2 the running foot, opposes an insuperable obstacle to their being employed in the numbers I consider absolutely requisite for efficient protection. Regarding this point, I refer the Board to the details of a very remarkable experiment described in the Appendix, and the inferences I draw from its consideration.

For all these reasons I propose, in lieu of rod iron or copper, to erect conductors of sheet copper attached to masonry pillars 3 feet square at the base tapering to 1½ feet at 30 or 35 feet high, and terminating in a light spar of 10 to 15 feet. Along this support I would fix a three inch copper strap, cut from the sheet. This strap should be led into the ground away from the building as far and as deeply as economy would permit, but never less than 10 feet deep.

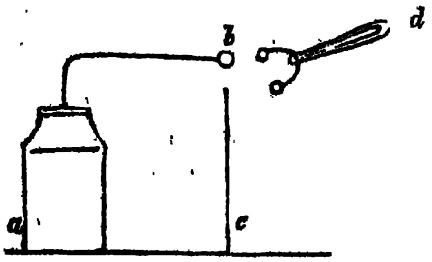
The expense of such a pillar conductor would amount to, Masonry 150 Rupees, 1 maund of (16 oz.) copper, at 35 Rupees, will give 320 feet of three inch straps. Say the conductors average 64 feet in length, this would give the cost of each only 7 Rupees.

A system similar in most respects is now adopted in the Royal Navy in preference to the old rod conductors. There can be no doubt of the superior efficacy and economy of the straps, although I agree with Sturgeon and others in considering Mr. Harris (their proposer) to be reckless of very possible consequences to a most blameable degree, with reference to the position and direction he has placed these conductors in, namely, running right through the vessel, and in one case passing close to the after magazines. I would again urge the necessity of erecting a 6 to 10 feet wall, wherever practicable,* at 10 feet distance from each magazine, and along which a copper strap should be laid down as described in the memoranda No. 7.

W. B. O'SHAUGHNESSY, M. D.

APPENDIX.

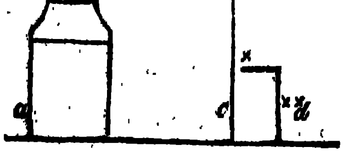
Description of experiments showing that an electric discharge (lightning) may leave a good and large and well-constructed conductor and pass to other conducting objects in the vicinity.



In the sketch, *a* represents a large Leyden jar, *b* a ball in connection with the inner coating, *c* a model lightning conductor of copper rod ¼ of an inch in diameter terminating in a point, and *d* the discharging rod by which the electric accumulation can be exploded from *b* to *c*.

On discharging the jar the explosion passed, as might have been anticipated, without fusing the bar and in a single discharge.

A second copper rod was now added; bent, as shown in the annexed sketch, one end (pointed) being brought to within ¼ of an inch of the conductor *c* the other end in metallic contact with the outer coating.



At every discharge through the principal conductor (*c*) a bright spark passed at ×. This could not have been what is called the "residual" charge, for it was simultaneous with the main explosion.

In the next experiment, it was found that cutting *d* at × × and placing detonating powder in the section, it exploded simultaneously with the main discharge.

Instead of a point the rod *d* may terminate in a ball and the same phenomena ensue.

Increasing the size or charge of the jar *a* caused the spark at × to increase proportionally and the striking distance to increase.

I regard this as direct experimental proof that electric discharges will subdivide themselves,—that is, that a proportion of the discharge will desert a conductor (in itself sufficient to carry off a still greater quantity) and will strike to other conducting bodies in the vicinity. Let us not dispute about the name to be given to the discharge, call it "lateral" or "residual," "direct," or "return," it matters not. The fact of importance is, that a powerful spark does pass between the conductor and adjacent conducting bodies. I ask emphatically if, with a quart jar this spark takes place through $\frac{1}{8}$ of an inch, is it exaggerating probabilities to apprehend that as a flash of lightning passes through a conductor placed close to a magazine, the analogous spark may penetrate the wall in obedience to the influence of the copper powder barrels within ?

It seems to me that these facts, with others previously adduced, leave us no choice or alternative. If we erect lightning conductors at all, we must erect them in numbers greater than those usually provided, and we must place them at a certain distance from the magazine we wish to protect.

W. B. O'SHAUGHNESSY, M. D.

The 29*th December* 1840.

No. 9.

PROFESSOR DANIELL'S LETTER TO P. MELVILL, ESQ., BEING A REPLY TO DR. O'SHAUGHNESSY'S 2ND REPORT.

King's College, London, 10*th May* 1841.

MY DEAR SIR,—According to the directions contained in your note of the 19th ultimo, I have read and carefully considered, the collection of papers which you have transmitted to me, regarding the subject of lightning conductors; and have now the honor to submit the following remarks for the consideration of the Chairman and Deputy Chairman of the Court of Directors.

* * * * * * *

I am happy to observe that the "wide variance" of Dr. O'Shaughnessy's opinion with mine, which he announces will practically be of very little importance, inasmuch as he states himself to differ in but a slight degree from the opinions of Mr. Faraday.

Dr. Faraday commences his Report in the following words:—"My opinion is in favor of lightning conductors;" and he concludes as follows:—"In my opinion a good conductor, well connected with the earth cannot do harm to a building under its protection, *i. e.*, though it may induce a discharge upon itself, it cannot induce a discharge upon the building, and the discharge in itself cannot give rise to any secondary effects which are likely to place the building in more danger than it would have been subject to had the conductor not been there."

How Dr. O'Shaughnessy reconciles "within a slight degree" this decided opinion in favor of conductors with his own is not of so much consequence as that he should act upon the decision to which he professes to differ.

The danger of delay is again apparent from the explosion in June last of the Coining House at the Powder Works at Mazagon by a stroke of lightning, the building being unprovided with any conductor; with regard to this as with the similar explosion at Dum Dum, Dr. O'Shaughnessy would probably draw a distinction between the building, and a properly-constructed magazine "arched and rounded, and in its outlines of low elevation;" but granting that the danger is greater in proportion to the elevation of the building, I cannot admit that such buildings are exempt from danger; or that the question of erecting conductors near them is altogether different from that of attaching conductors to private dwellings or ordinary buildings. In the grand system of natural operations carried on in a thunder storm, even considerable elevations bear little proportion to the enormous surfaces which are brought under induction, and do not influence the discharge to any great extent, in proof of which the lightning has often been seen to strike the level of the sea even in the vicinity of high masts of ships armed with conductors. It is true that the chances of a low building, or of an equal area of soil or terrace being struck, are small; but what prudent man would run even this small risk where the stake is so serious and the cost of insurance so slight?

Dr. O'Shaughnessy seems disposed to admit that safety may be given to a building from direct and *ordinary* discharges by conductors "erected in such a way that no point of the roof shall be further from the conductor than twice the length of the height of the conductor above the level of the roof;" but he adds, "this applies only to flashes from clouds in a calm atmosphere, and above the building. The area of protection is unquestionably much contracted under the circumstance so common in India of a thunder-cloud being blown with hurricane velocity across a plain before a furious storm."

This distinction I am quite at a loss to understand. I will not suppose that Dr. O'Shaughnessy means to compare the velocity of lightning with that of the most furious squall that ever blew; or that he wishes it to be inferred that the latter could have the slightest influence upon the former. If, as we have every reason to believe, lightning travels with something more than the velocity of light, its transit between the cloud and the earth must be completed in an inappreciable moment of time; and whether in a calm atmosphere or in a hurricane, its direction will be that of least resistance at the single moment in which the discharge is at once commenced and completed. The object of the lightning rod is to present a course of less resistance than that of the object which it is meant to protect. No "paroxysmal storm" (if I understand the term) would have power to cause it to deviate from this course. Dr. O'Shaughnessy has strangely misunderstood my words, which he quotes in the margin of his second Report, and makes great use of the misconception. He says:—"Mr. Daniell has indeed stated that a pointed bar must cause a silent discharge without explosion." I am quite sure that if he will take the trouble to re-peruse the paragraph, he will be candid enough to allow that I have stated no such thing.

I have said that, "a pointed conductor will draw off silently and safely a considerable portion of electricity from a charged cloud; but it can possess no power of determining a disruptive and destructive discharge at a point where it would not otherwise occur."*

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* I of course mean *without* the small circle of protection, *within* that circle it has power of determining the discharge upon itself rather than upon other parts.—*Note by Mr. Daniell.*

At points where it *would* otherwise occur, of course, the discharge would take place, and I am not indeed surprised that Dr. O'Shaughnessy should be "unable to comprehend how Mr. Daniell could have fallen into such a misconception."

Upon reconsideration I trust that he will allow that there is no immediate necessity for my repeating the very "*simple experiment*" which he has done me the favor to suggest. I entirely agree with him that it is quite essential that no misconception should arise, and I freely admit, what I have never dreamt of denying, that an explosion may occur to a pointed conductor. What I deny is, that if the conductor be properly constructed, any injury will arise to a neighbouring building from such an explosion.

In the next point I fear I have the misfortune to differ again very materially from Dr. O'Shaughnessy. He undertakes to show that—"the quantity of the electricity passing may be so much greater in quantity than the single conductor *can* convey in *the time* of the discharge; that a considerable part, nay, the whole of the excess, must pass to the ajdacent objects" Now, the only measure of the *capability* of a conductor to convey a discharge is its capability *of resisting* fusion If it be fused by the discharge, a considerable part, I admit, must pass to the surrounding objects. Even in the case of non-fusion I have no doubt that a small portion would pass through a small interval of air from the main conductor to another good conductor placed at a very short distance from it. The charge would divide itself upon the two conductors in proportion to the facilities of transit which the two passages would offer, including, of course, the high resistance of the interval of air through which it must leap; but one of the obvious precautions in erecting a lightning rod is to place it at a great distance from any such good conductor.

The instance adduced from M. Arago's collection of Mr. Raven's house in Carolina, is an example of an insufficient conductor being melted, and of the consequent passage of the excess to a conductor in the neighbourhood. The accident to Dr. Goodeve's house, upon which Dr. O'Shaughnessy has laid so much stress, would not have proved the contrary even had the distance between it and Mr. Trower's conductor been only 30 feet, as originally stated. The distance of 66 feet, which has since been ascertained, as the true distance between them, placed the house beyond the protection of the conductor according to M. Biot's opinion, which Dr. O'Shaughnessy deemed the case completely to *falsify*. Dr. O'Shaughnessy must now himself allow that this could not be an instance of lateral deviation from a conductor. In acknowledging this great mistake in his letter of the 11th September 1846, Dr. O'Shaughnessy refers to me, in terms so unusual either in official or scientific communications, that I shall refrain from further comment, only assuring him that he greatly mistakes my spirit; and that, so far from triumphing in the overthrow of this main fact, upon which he has founded so long an argument, I am even now disposed to grieve at the unnecessary acuteness of his feelings upon the occasion.

In discussing, however, the question, what is the greatest mass of metal a flash of lightning can fuse, Dr. O'Shaughnessy has mistaken the law of the distribution of *statical electricity* upon the surface of bodies, for the law of the conduction of *current electricity* through them. Nothing is more certain, and nothing more generally admitted by all competent authorities upon the subject, than that the conducting power of all bodies is, *cœteris paribus*, directly as the area of the section through which the electricity passes. I believe that Dr. O'Shaughnessy would find it difficult to produce *one fact* which shows it to be "the surface which the electricity pursues."

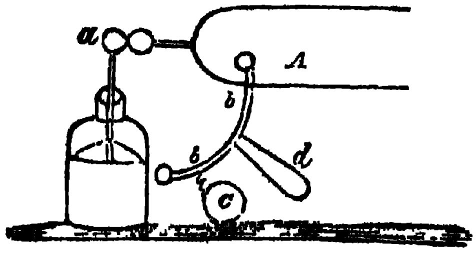
It is this fundamental error which has led him to imagine that "the surface of a conductor may be inadequate to convey a quantity of electricity although this be insufficient to melt or even to heat the whole length of the metal."

Dr. O'Shaughnessy's observations upon the power of conductors to attract lightning being only personal to myself, the public service does not require that I should notice them, and I shall, therefore, willingly pass them by with one remark, *viz.* that "drawing off silently and safely a considerable portion of electricity from a charged cloud," and "attracting a flash of lightning" are *not* "very like synonymous terms," as he asserts them to be.

With regard to the dangers to be apprehended from a *lateral discharge* I have no expectation of converting Dr. O'Shaughnessy to my unchanged opinion, that with properly-constructed conductors, there is nothing to be apprehended from it; but the matter has been so fully discussed by the most eminent electricians* that I think the Court will have no difficulty in coming to a correct conclusion without attaching any particular importance to our unanimity upon the subject. The deliberate opinions of Dr. Faraday and Professor Wheatstone, with the reasons of their conclusions upon the subject, are fully recorded in the Report of the Committee upon lightning conductors, which was in the possession of Dr. O'Shaughnessy at the time of writing his last Report, and to that I have nothing to add.

As, however, Dr. O'Shaughnessy has "selected an experiment with the Leyden bottle to exemplify his statement," and illustrated it with two diagrams, and as from his so doing it might be inferred that he supposes that it has escaped the attention of Dr. Faraday and Professor Wheatstone, as well as of the Committee who made the Report, although, as he states, "all electricians have seen it, and the *existence of the spark* is UNIVERSALLY ADMITTED," I think that I cannot be excused from giving at length the grounds of my opinion that he has totally misunderstood the results of this common experiment.

Upon comparing Dr. O'Shaughnessy's diagrams with the directions he has given for conducting the experiment, it will be obvious that he has omitted one part of the apparatus in use "by increasing the mass of which," as he very properly states, "the success of each attempt at obtaining the lateral spark will increase," *viz.* the *prime conductor.* From this it appears that he supposes his jar in contact with the prime conductor, and the diagram should have been of this kind.



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* Consequently we find in appealing to the experience of nearly a century, that not a single case can be adduced, in which a lightning-rod in the act of transmitting a heavy charge of lightning, has thrown off a lateral explosion on semi-insulated masses near it.—*Harris on Thunder Storms, page* 201.—ED.

Here *A* represents the prime conductor. Now when this system of bodies is under charge we can distinguish it into two portions,—the main charge, which is sustained by the glass placed between the metallic coatings of the jar, and a secondary charge, which is sustained by the air which is interposed between the prime conductor and surrounding objects, of which the metallic ball *c* is one; the ball *c* is the opposite state with regard to *A* just as the outside coating of the jar is with regard to its inside coating. Upon the application of the discharging rod two simultaneous discharges take place, the main discharge, which is incomparably the greatest, which neutralizes the two electricities upon the opposite sides of the jar and a secondary discharge which places the prime conductor *A* in equilibrio with *c* and other objects with which it is in communication. This secondary discharge will, therefore, obviously be proportioned to the size of the prime conductor, as Dr. O'Shaughnessy correctly states; and independent of the prime conductor itself, a very small portion of "free" charge, as it has been called, or charge sustained by the air to surrounding objects will always be found upon one or other surface of a charged jar, from which a wire and ball projects, as usual, beyond the coating.

The circumstances, however, of an atmospheric charge can never resemble those of the arrangement I have been endeavouring to explain, and the conditions of a thunder-cloud and an equal area of the earth's surface with the interposed air, are exactly similar to the coatings of the jar, and their interposed glass *alone*, without the possibility of any associated system of bodies at all resembling the prime conductor and the ball; such a secondary spark as that adduced by Dr. O'Shaughnessy could not therefore occur.

Dr. O'Shaughnessy may possibly consider this explanation of "an experiment which all Electricians have seen" as a successful application of my "ingenuity in placing the question in a less intelligible point of view;" but it is nevertheless one that has frequently been given by the first electricians, and is indeed obvious.

In adverting to Mr. Snow Harris's conductors for ships, it is much to be regretted that Dr. O'Shaughnessy should not have referred to "the evidence of facts derived from the experience of many years which proves the efficacy"* of his plan. It is fully detailed in the Report of the Committee, and Dr. Faraday observes that he "could not but appeal to the evidence of experience; ships fitted with his conductors had been exposed to severe lightning, and the *electricity had been known to descend by them* with perfect security to every thing on board, nor was there, so far as he could learn, any instance on record of lateral explosion."*

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* See Note, page 30.—Ed.

With this evidence before him it is scarcely to be conceived that Dr. O'Shaughnessy could have expressed a wish that "his humble voice could reach the Lords of the Admiralty" in disparagement of them, or that he should have ventured to insinuate that they were advocated by men who had "other than public interests at heart and pledged scientific notions to maintain."

I think that it would be a useless occupation of your time to enter upon any further discussion of Dr. O'Shaughnessy's opinions. The evidence is so complete, as published in the several Reports upon the subject that without regarding any difference of opinion between Dr. O'Shaughnessy and myself, the Chairman and Deputy Chairman and Court can have no difficulty in coming to a right decision upon this important question; and when I recollect that the efficacy and safety of lightning conductors has been maintained from the times of Franklin, to our own times, by such men as Poisson, Dulong, Gay Lussac, Davy, Woolaston, Arago, Faraday, Wheatstone, and Snow Harris, and that no fact has been substantiated of any damage having arisen from such conductors of proper construction either from lateral explosion or otherwise, (all asserted instances to the contrary having invariably, like the accident to Dr. Goodeve's house, been disproved upon proper investigation), I cannot doubt that decision will be to direct the careful erection of sufficient conductors to all the magazines of powder throughout the Company's dominions.

I need scarcely assure you that should the Chairman or Deputy Chairman desire any further explanation upon the subject, it will give me the greatest pleasure to afford it, to the best of my ability, either personally or in writing, as they may require.

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* In all the cases in which dense explosions have been transmitted by conductors fixed to the masts of the ships, no lateral discharge has occurred; yet they are very near a succession of metallic bodies; *viz.* sheaves and pins, funnel for rigging, iron-bound caps, eye bolts, chain slings, mast hoops and even the great masses of the chain cables and water tanks.—*Harris on Thunder Storms.*—Ed.

J. F. DANIELL.

P. S.—In a letter from the Military Board to the Governor in Council, I observe that a question is submitted as to the case of a magazine situated upon a rock, to which I have no hesitation in replying that if a perfect communication were made between the conductors and the water in the excavated reservoir, that provision would be quite sufficient for carrying off the electric fluid.

J. F. D.

No. 10.

PROFESSOR DANIELL'S LETTER TO P. MELVILL, ESQ., SUPPLEMENTARY TO THE PRECEDING ONE.

King's College, London, 15th June 1841.

MY DEAR SIR,—I have looked over, and attentively considered, the additional collection of papers upon lightning conductors, dated Bengal, 17th March 1841, which you have done me the honor to transmit, and have found nothing to induce me to alter my Report of the 10th May.

In Dr. O'Shaughnessy's letter to Major DeBude, of the 30th December 1840, he insists more strongly than ever—"that every fact in the history of lightning shows it to be *surface* of conductors and not *mass*, which is required for the safe conveyance of the electric discharge."

This I have already pointed out, as a fundamental error which affects most of his reasoning upon the subject. If there is one law of Electricity better established than any other, it is that the conducting power of all bodies is directly as the square of the diameter of cylindrical rods, or as the area of the section, whatever the form may be.

In erecting lightning conductors it would be a fatal mistake to rely upon the surface without regard to the thickness of the metal.

J. F. DANIELL.

No. 11.

PROFESSOR FARADAY'S REPLY TO DR. O'SHAUGHNESSY'S SECOND REPORT.

To J. C. MELVILL, ESQ., *Secretary, &c. &c. &c. East India House.*

Royal Institution, 9th June 1841.

SIR,—I have received your letter of the 3nd instant, and also from Mr. Daniell the various papers it refers to. I have re-perused Dr. O'Shaughnessy's first papers, and my Report of the date of 5th September 1839, and have now read Mr. Daniell's Report of the 24th August 1839, and Dr. O'Shaughnessy's further communications and remarks. These, with the other papers, I have carefully considered, and as the general result, beg to say that I see no reason to alter even a word of my former Report.

2. In saying so much, perhaps, I say every thing that the Honorable Court of Directors desire of me; for it is probably more the judgment of the individual, than the reasons for the judgment that is required. The latter it is almost impossible for any man to give fully, in a case where there are arguments and reasons on both sides of a question, for the bearings of these become almost infinite in number by reason of the variation in degree of force which they possess under varying circumstances, and at last it is the discretion, experience, tact and caution of the person, which give to his opinion any worth it may in reality possess.

3. But as the present is a question which is *referred back* to me, I ought, perhaps, not to think it one in which the mere opinion without reasons will suffice; and yet I find a difficulty in going further into the matter, for seeing and deeply regretting a particular tone and character which some parts of the communications have acquired, I am exceedingly anxious to keep myself quite clear from it, and may perhaps find this rather difficult. However, in what I may further say, I shall avoid referring to the opinions I agree with or differ from, as much as I can, yet, without withholding my own opinion on any of the important points which are essential to the case and are intended by the Court to be submitted to me.

There are, I think, three points under which all that is for consideration, may be arranged.

First.—Whether a good lightning conductor can cause a discharge where there would not be one otherwise.

Second.—Whether, when the electric fluid falls upon a conductor, a part may not pass from it in the form of lateral discharge and occasion harm.

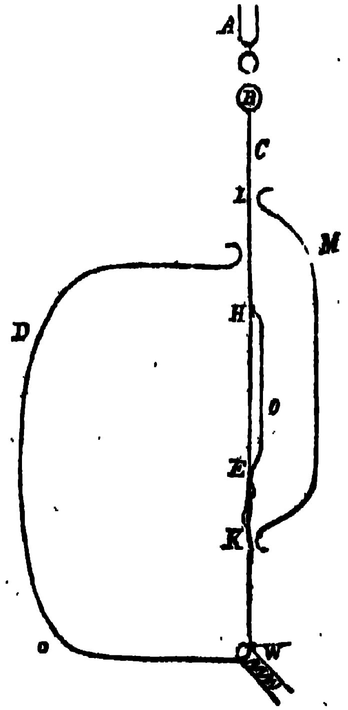
Third.—Whether, at the moment the lightning conductor is struck, it may, by induction upon the gunpowder casks lined with copper or other metallic masses within the magazine, cause sparks to pass between them without any actual lateral passage of lightning from the conductor.

As to the *first,* I have already said that I think a good conductor may, under certain circumstances, cause an electric discharge to take place where otherwise there might not be one; that in fact it can virtually attract the lightning. It is to this quality that it owes much of its usefulness, if it have any; for unless it could divert the discharge (within certain limits) from a place where the lightning would otherwise have fallen, the conductor would have no use. But that it should cause a discharge upon itself, and also at the same time upon a neighbouring object, as in the given case of Dr. Goodeve's house, and that, not by a lateral discharge, is what I see no reason to expect either from principle, my experience, or such events as have come to my knowledge.

It is said that Dr. Goodeve saw the flash divide; part going to his own house *in the verandah of which he stood,* and part to the lightning conductor of the neighbouring house. When flashes occur so close to, and over a person taken unawares as in this case, it is exceedingly difficult to distinguish exactly what takes place as to the direction of the electric flash, for there are many remarkable and confusing effects that simultaneously occur; still, admitting the division, I cannot but think the conductor acted as it ought to do, rather than as it ought not, and that there would have been a much heavier explosion on Dr. Goodeve's house if the conductor had not in part averted it, though at the distance of 60 feet, than did occur under the existing circumstances.

The most important point however is, *second,—Whether when the electric fluid falls upon a conductor a part may not pass from it in the form of lateral discharge and thus cause harm.* Before I make further remark upon this head, I must repeat the words I used in the former Report. " I have no fear of lateral discharge from a *well-arranged* conductor. As far as I understand lateral discharge, it is always a discharge from the conductor itself. It might be very serious from a badly arranged conductor (and in fact makes them worse than nothing); but with a good lightning rod it can be but small, and then not to badly conducting matter, as wood or stone, but only to neighbouring masses of good conducting matter, as the metals, which either ought not to be there, or if they are necessarily present ought to be in metallic communication with the lightning conductor itself. I am not aware that lateral discharge can take place *within* a building when a lightning conductor outside is struck, *except* there be portions of metals as bells, wires, bolts, &c., which may form an interrupted conducting train from the conductor to the interior."

That a lightning conductor well arranged as to its termination with the earth, especially if not of sufficient thickness, may give lateral discharge in the form of brushes and sparks, even when the quantity of electricity passing through it is not a thousandth part of that required for its fusion, or which the conductor could safely convey if alone, I can well believe and understand; but for this to happen it requires an arrangement which I have already protested against above. The effect, when it does occur, is due to the resistance which even the best conductor makes to the passage of the electric fluid, and will be understood if I briefly describe a few experiments which I have made for my own satisfaction. We cannot always, it is true, say that an apparatus accurately represents natural circumstances, for the two sides of a Leyden jar do not correctly resemble the state of a cloud and the earth: the conducting power and aggregation of the charged surfaces are different, and so is the state of the medium between them; but the general principles are the same. In these experiments I used the mere spark of a large and good machine, employing no Leyden jar.



A is the knob of a large prime conductor: *B* a metallic ball, 6 inches in diameter, the distance from it to *A* being variable between the limits of 4 and 10 inches; *C* and *D* were wires of copper, 40 feet in length, and each well connected at one of their ends with a large and extensive series of water-pipes *W*; one of them was $\frac{1}{20}$ of an inch in diameter, and the other $\frac{1}{10}$ of an inch.

When either of these was connected with the ball *B* and electric sparks passed from *A* to *B*, the electricity was conducted away perfectly by the wire; but when the end of the other *D* was brought to within a small distance of *C* in any part between *E* and *B* a lateral spark passed from the conducting wire to the approximated wire at the same time that the principal spark passed from *A* to *B*. The lateral spark was brighter and larger according as the part of the conducting wire from which it was obtained was nearer to the ball *B* and further from the water-pipe; and this is an important point, for the water-pipe here represents the earth in a well-arranged lightning conductor. When the wire *D* was taken off from the water pipe and made fast to another set of pipes as its final discharger, still the same effects occurred; when a person standing on the carpet of the room tried to draw this lateral spark from *C* by approximating the knuckle, he could scarcely obtain any traces, unless he held the wire *D* in his hand, and then the badly-conducting matter of his hand could draw a very feeble spark. This lateral spark was still more beutifully shown to depend upon the resistance of the matter of the wire, by taking a piece of wire *O* about 10 or 12 feet long and making it fast on to *C* at *E* and then bringing the other end near at some part towards *B* as at *H*; for a lateral spark passed at *H*, showing a certain division of the discharge through the two wires *C* and *O*. When a similar wire *M* was brought near to the wire *C* at *K* and at I, not being in contact at either place, then every time the lightning flash passed between *A* and *B* a small spark passed from the principal to the secondary wire at I, and one from the latter back to the former at *K*. To complete this kind of observation the single wire *C* was removed, and replaced by a bundle of fine parallel wires well connected at the two ends, and as their respective diameters were $\frac{1}{10}$, $\frac{1}{8}$, $\frac{1}{8}$, $\frac{1}{5}$, $\frac{1}{5}$, of an inch, they were together equal to a copper rod above one-third of an inch in diameter, and 40 feet long, representing, not inaptly, a lightning rod of small thickness; still, when the flash passed between *A* and *B*, lateral sparks could be obtained from any, or all, of these wires at the parts towards the ball *B*.

I charged the discharger *C* which represents the lightuing conductor, and made it to consist of a fine copper wire only $\frac{1}{42}$ of an inch in diameter. The same general effects were obtained, the lateral spark being, however, longer than before. I made the lightning distance from *A* to *B* vary from 8 inches to 2 inches and took the lateral spark continually from a certain spot near *B*, *i. e* about 6 feet from it. The lateral spark was nearly half an inch long, and quite as long for the 2 inch lightning spark as for the 4 inch or 8 inch lightuing spark,—a result dependant on the circumstance that the 2 inch spark, though containing less electricity, is a quicker spark than the 8 inch or longer one, time being here concerned in a manner evident to an electrician.

I also made the lightning distance a constant interval of $\frac{3}{4}$ of an inch, and then compared the effects of a small spark from the conductor only with those of a denser spark of a large jar, to illustrate the influence of quantity. The lateral spark was the same length in both cases, but much brighter when the jar was used than when only the conductor spark was employed. In all these experiments with the fine wire *C*, an excellent discharger was used for *D*, (being a wire $\frac{1}{5}$ of an inch in diameter) for the purpose of exalting the effects.

That these lateral discharges were really due to the cause I have assigned, namely, the resistance in the metal to the passage of the electric fluid, and not to induction directly from the machine, was shown by the following arrangement: a part of the wire about I was completely sheltered from the effect of the machine by large uninsulated metallic plates, and yet the lateral spark could be obtained, though not so bright as when the plates were away. In the latter case, inductive action and return discharge were combined with lateral discharge.

Here then are lateral discharges, and occasionally from a rod, 40 feet in length, equal to $\frac{1}{3}$ of an inch in diameter, well connected with a discharging system at the part representing the earth in a lightning rod; and that, when the electricity sent through was certainly not a five thousandth part of that which the rod alone could have carried safely. What then (it may very properly be asked) can justify our placing such an instrument as this near a powder magazine?

In the first place, it may be replied that all these striking instances of lateral discharge are obtained by using a good lateral conductor, having, in all the cases but one, a good discharging termination with the earth; and which, therefore, is itself a lightning conductor acting conjointly with the principal one. In the next place, where it was not in connexion with the earth or conductor it was running parallel to it, and virtually connecting parts at different distances from each other on the lightning rod, and so showing its functions. In the next place, it is found, as has been stated, that the lateral discharge is always greatest near the top of the lightning conductor (or its representative,) and diminishes to nothing towards the lower end; and in the last place, even with the finest wire, and the most exaggerated and best lateral conductor, the lateral spark contained but a small portion of the electricity of the principal or lightning spark.

Now, it is by diminishing or removing entirely the influence of all these circumstances that a lightning conductor becomes a safe neighbour. It should consist of a sufficient body of excellent conducting matter, and it is considered that in this respect a copper rod one inch in diameter is enough; it should be well connected by copper-plates with the moist ground or water;* it should rise high† above the building to be protected; it should be placed near to it that what directive influence it has over the lightning may be used in protecting the building; it should not come near masses of metal in the building, as a metal roof, or an iron column, or spout, or leaden pipe, or bell wires; or, if it does, these should be metallically connected* with it, and should themselves not go near to other metallic masses in the building and remain unconnected with them. In fact, the principle is to make all that may act as a conductor, and which *would* act if the lightning rod were not there, a part of the conductor; that no *interruptions* may occur in the electric course; and to give this course a free discharge into the ground,—the stored powder and such conducting masses being at the same time purposely separated from each other as far as they properly or conveniently can.

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* Damp earth offers to the fulminating matter, which is passing along a metallic bar, a channel by which it escapes easily and without effort, without detonation and without producing any kind of damage, provided the bar plunges a little deeply into the earth. If the conductor goes down into earth only moderately humid, and therefore only moderately permeable to fulminating effluxes, it will be necessary for the contact between them to extend through a considerable length. This length may be less if the ground remains strongly saturated with moisture throughout the year, and less still if the conductor goes down to a *natural* sheet of water. The highly necessary multiplication of the number of points by which the fluid may flow off into the ground. might be obtained by, as it were spreading out the metal, bringing the lower part of the conducting bar, by the action of proper machinery, into the form of a wide plate, and thus extending as much as possible the surface brought down into the ground.—*Arago's Meteorological Essays.*—Ed.

† In France builders go up to 10 metres (nearly 33 feet) and even only stop there on account of considerations connected with solidity.—*Ibid.*—Ed.

As a general illustration, I may take Dr. Goodeve's house with its vertical window bolts, and say, that if a good lightning conductor were fixed in that house, and made to run parallel with the bolts at the distance of a foot or so, it is very possible, that, when lightning struck the conductor, it might discharge in part to the bolts and much harm might be done; but if those bolts were in good metallic communication with the lightning rod, no harm would be done; and further, if the lightning rod were away, it is almost sure that the bolts without them would be struck as in fact appears to have been really the case; for I cannot think the striking was due either to lateral discharge or the attractive influence of the lightning rod standing 60 feet off.

A question has arisen with regard to the surface and the mass of a lightning rod: in the present case the question is of a mixed nature; as a conductor, surface has no influence over the power of the lightning rod, and copper plates or ribbons may not be substituted for a copper rod of equal superfices. The conducting power is as the square of the diameter in round rods, or, in fact, directly as the sectional area, whatever the surface may be. A copper rod, an inch in diameter, is considered as sufficient, the conclusion being the result of general observation of natural and experimental phenomena. Flashes of lightning, though very awful and exceedingly intense in action, have not so much quantity of electricity in them as many phenomena which continually pass unobserved before us, and frequently cannot fuze copper wires $\frac{1}{5}$ of an inch in diameter or even such as are only $\frac{1}{8}$ or $\frac{1}{10}$ of an inch thick.

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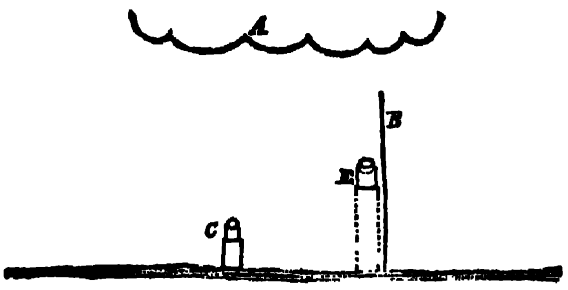
* The only safe practice is to unite all these various metallic masses by rods of iron or copper, or by bands of lead, zinc, &c., so that there may not be any one of them, which shall not be, if I may use the expression, in metallic communication with the bar which is destined to transmit the fulminating matter or lightning to the damp earth.—*Arago's Meteorological Essays.*—ED.

But as every metal opposes resistance to the passage of electricity, and is, therefore, an imperfect conductor, so surface and the shape of that surface has an influence, and does to a certain extent affect the lateral discharge. In fact, whilst the conductor, as our wire *C*, (page 46) can give a lateral spark, the electricity which can cause that spark, is, in relation to external bodies, governed by the laws of statical electricity, and hence the influence of surface. Its effect, however, in a lightning conductor, unless purposely exalted and sought for, can be but small.

The third point is, *whether at the moment the lightning conductor is struck, it may by induction upon the gunpowder casks lined with copper or other metallic masses within the Magazine, cause sparks to pass between them without any actual lateral passage of lightning from the conductor.* Such a case would, according to my view, be a case of returning stroke, and be distinct from lateral discharge; the principles of such a case are easily illustrated. Suppose *A* a charged electrical surface, either that of a cloud or of a prime conductor; *B* a lightning rod well arranged, and *C* a couple of metallic cases standing one on the other but separated by a sheet of paper, a cloth or a thin piece of wood. As the surface *A* becomes charged positively, (we will assume it to be so), the upper end of the lightning rod *B* and the upper case *C* will become negative by induction. Upon the discharge occurring to the lightning rod, the induction upon *C* would cease more or less, and it is possible that at that moment a spark should pass between the upper and lower metallic cases. But this can only happen if the cases *C* have been exposed to the induction of the cloud or machine as it rises in intensity, *before* the spark passes; if they are protected from this, as I think they are most perfectly by being within a building and under a roof, then no case of this kind can occur.



If the metallic case or other mass of good conducting matter be both exposed to the inductive action of the charged surface, and also near the lightning rod, as at *E*, then the effects of return and lateral discharge may be combined; for before the discharge on to the lightning rod, *E* will become negative by induction, and at the moment of the discharge a lateral spark will pass from the conductor to it, to restore its state; a metal roof unconnected with the neighbouring conductor might present this case. These are results very easily obtained with electrical apparatus and machines.

I hasten to bring this letter or report to a conclusion. The whole question is whether such a low object as a powder magazine is safer with or without a lightning conductor. I cannot say that I have had very much experience of very powerful thunder-storms, or such as may compare with those in India; but I know that in this country very low objects are struck, and, therefore, I should protect by a lightning rod such as I was very anxious to preserve. In place of increasing the number of those around a building, I would rather increase the height of the one or two used by a few feet. The distance from the magazine I would make about, but not further than, three feet. The other points mentioned in my former Report I would again beg to urge upon your attention. The water tank at Mazagon Powder Works would, in my opinion, afford sufficient discharge, provided the communication of the lightning rod with it be made by metallic plates immersed in the water.

Wm. FARADAY.

NOTE BY THE EDITOR.

The Honorable Court of Directors being satisfied with the opinions of Professors Faraday and Daniell, directed in their Despatch No. 54, dated 23rd June, 1841, that all Magazines throughout India should at once be provided with lightning conductors. From this time also the discussion of the subject of lightning conductors remained in abeyance until August 1844, when it was again agitated in the following papers, Nos. 12, 13, 14, 15 and 16, owing to objections raised by Captain Pillans, Commissary of Ordnance at Cawnpore, to attaching lightning conductors to the Magazine at that station.

No. 12.

LETTER FROM THE MILITARY BOARD TO THE GOVERNOR GENERAL OF INDIA IN COUNCIL.

Fort William, 31*st December* 1844.

RIGHT HON'BLE SIR,—We do ourselves the honor of submitting to Government the transcript of a communication No. 134, dated on the 27th June 1844, from Captain W. S. Pillans, at that time Commissary of Ordnance at Cawnpore; giving it as his opinion, that it would not be expedient, for reasons stated, to attach lightning conductors to the Magazine at that station.

As the points agitated by Captain Pillans, and concurred in by Captains Weller and Fraser (of the Engineers,) involved serious considerations, we deemed it most expedient to seek the opinion of Dr. W. B. O'Shaughnessy on the question, as an individual probably the most conversant in India with the subject; and, accompanying, we beg to annex that gentleman's Report, which enters most fully into the case, and comprises a most valuable and scientific paper on the points at issue.

As respects the Cawnpore Magazine, Dr. O'Shaughnessy concurs with Captains Pillans, Weller, and Fraser, in considering it to be less exposed to risk without conductors, than if armed with them in the ordinary method and in the common number; but that there is still the equal risk to which this Magazine is exposed in common with every equal surface; and he earnestly trusts that, to obviate this danger and guard effectually against the calamities it may lead to, the Board will adopt the simple and certain plan he has recommended, by which the Magazine will be placed in a condition, in which, were it to be struck by lightning daily, still no disaster could ensue.

Under these circumstances, we consider it would be advisable to suspend the further application of conductors to Powder Magazines; and we venture to recommend, that the subject be fully investigated by a Committee of competently scientific persons. This Committee should enquire into the facts and views advanced, and furnish a Report thereon to the Board, who would transmit the same for the information of the Government, which would then, we conclude, be better enabled to decide on the question of continuing, or definitively abandoning the use of lightning conductors than from the conflicting opinions at present available.

W. H. L. FRITH, *Brigadier Commanding.*
R. BENSON, *Lieutenant-Colonel.*
W. BURLTON, *Lieutenant-Colonel.*

No. 13.

LETTER FROM CAPTAIN PILLANS, COMMISSARY OF ORDNANCE AT CAWNPORE, TO THE SECRETARY MILITARY BOARD.

Cawnpore Magazine Office, 27th June 1844.

SIR,—Having been informed by Captain Weller, that he has received orders to put up lightning conductors to the Powder Magazine, I beg leave to state, for the consideration of the Board, that the particular locality of the Magazine, a very low building, surrounded by others much higher, with a circular roof, and without any prominent point whatever, renders it comparatively safe from risk of being struck by lightning; and as forty years have in some degree proved this to be the fact, I think it my duty to mention the circumstance to the Board, as it appears to me that as a conductor must also be an attractor of lightning, the point may be doubted as to the expediency of alteration to a building particularly devoid of risk as it is at present.

Both Captains Fraser and Weller agree with me in this reasoning, as I think would also the Board could they see the situation of the building.

W. S. PILLANS, *Captain.*

No. 14.

THIRD REPORT OF DR. O'SHAUGHNESSY.

TO CAPTAIN GREENE,
Secretary to the Military Board.

Calcutta, 24th August 1844.

SIR,—I have now the honor to acknowledge the receipt of your letter of the 26th ultimo, which reached me on the 1st instant, in which the Military Board are pleased to refer to my decision the doubts suggested by the Commissary of Ordnance at Cawnpore, concurred in by Captains Weller and Fraser, of the Engineers, as to the expediency of attaching lightning conductors to the Powder Magazine at that station.

Those Officers are stated to be of opinion that, from certain advantages of situation, the attachment of conductors would, in this instance, be more likely to endanger than protect the Magazine. This is described as a low building surrounded by others much higher, with a circular roof, and without any prominent point whatever. They consider that as a conductor must also be an attractor of lightning, the point may be doubted as to the expediency of alteration to a building particularly devoid of risk as it is at present. They appeal to the evidence of the forty years which this Magazine has passed unharmed as a proof of the correctness of their opinions.

Participating in the doubts thus expressed, I have postponed a reply to this reference until some routine business was disposed of, in order that for the satisfaction of the Officers above-named, as a mark of respect for the Military Board, and in vindication of the sentiments I have long entertained on this subject, I might be enabled to discuss it in detail, advancing adequate reasons for every opinion. I may be permitted to add too, that, since I last had the honor of addressing the Board regarding lightning conductors, much progress has been made in our knowledge of electrical phenomena. Mr. Harris has published a work on "*Thunder Storms*"* which, though containing erroneous views on this question, is nevertheless a very valuable repository of facts, well calculated for its elucidation.

I should notice also the construction of the extraordinary Steam Electric Engine at the London Polytechnic Institution, which the Directors liberally permitted me to use in several experiments essential to the full satisfaction of every doubt on this subject. Lastly, personal discussion of all its bearings with Messrs. Faraday, Wheatstone, Apjohn, Davy, Draper of New York, and Henry of Philadelphia; and its close experimental investigation in Dr. Davey's laboratory, and in his presence; all these circumstances enable me to present the following views regarding the protection of our Magazines, with a degree of confidence almost equal to that experienced in the description of the unequivocal results of a chemical experiment or enquiry.

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* From which so many quotations have been made in both foregoing and subsequent Notes.—Ed.

I shall arrange this paper in the form of a commentary on the following questions:—

Can ordinary lightning conductors attract or determine discharges of lightning on themselves?

Are lightning conductors capable of exhausting silently the electricity of the clouds so as to render them harmless?

In conveying discharges, do the best constructed conductors invariably carry off in a harmless state all the electricity which falls upon them, or do they permit a portion of this matter to leave them and strike adjacent bodies? If so, under what circumstances is this most likely to occur?

When lightning conductors convey an electric discharge to the earth, is the mere passage of this electricity capable of causing electric action in adjacent metallic bodies and producing sparks between them?

Assuming all these questions replied to affirmatively, do we possess any means of certain and infallible protection for our Powder Magazines from the disastrous effects of lightning?

That we have means of such protection perfectly within our reach I trust to be enable to prove; and I now proceed to the discussion of these questions, premising that I claim for granted the identity of lightning with the discharge of the Leyden battery, a point conceded by Mr. Harris, whose opinions fall so frequently under discussion in the the subsequent observations.

QUESTION 1ST.—*Can ordinary lightning conductors attract or determine lightning upon themselves, or are they mere passive channels for its discharge?*

While general opinion, founded on the evidence of numerous well-authenticated facts,* inclines to the belief that the lightning conductor attracts or determines the discharge upon itself, and thereby draws it away from other objects, it is nevertheless contended by many eminent Electricians (especially by Mr. Harris and Professor Daniell,) that the conductor is strictly passive, that it serves but as a channel of discharge, and corresponds exactly with a water-course or pipe by which a reservoir is emptied. This is a favorite illustration of Professor Daniell, and is used with much emphasis in his special notices on this subject, and in his last work—"The Elements of Chemical Philosophy."*

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* When this large mass of evidence is duly considered, together with the fact, that lightning strikes indiscriminately, trees, rocks, and buildings, and even the ground near them, we are compelled to admit that the thunder rods of Franklin are perfectly precise in their operations, and that the common notion, that they invite destruction to our buildings, is not warranted by any sound argument drawn from experience.—*Harris on Thunder Storms, page* 184.—ED.

On the other hand, there are many Electricians† who believe, that pointed conductors may determine upon themselves discharges of lightning, which otherwise would not have fallen on the same spot.

I proceed to review the evidence on which these opposite opinions are based.

The advocates of the doctrine of the passive state contend—

1st.—"The very great area of excited cloud and earth renders the action of a mere point, such as a conductor, too insignificant to be regarded."

2nd.—Lightning, they state, often avoids such pointed bodies and passes in other directions. The instances are adduced of Her Majesty's ships *Neptune, Southampton, Sapphire* and *Vanguard*, and the Steam-packet *Dart*; close to which vessels lightning fell into the sea, although they were provided with conductors. Again, the case is prominently cited of lightning having struck the granite chimney of the Victualling Department at Plymouth, avoiding the conductor of the clock tower 300 feet distant. In the same storm the sheer-hulk was struck. It had a small metallic wire, leading to the top of a pole, serving as a top-mast, and this wire was connected below with large metallic chains attached to the mast and sheers. The whole were completely overtopped by the adjacent spars of Her Majesty's ship *Cornwallis*, fitted with conductors to each mast.

3rd.—The *Powerful* and the *Asia*, line-of-battle ships, were at anchor.

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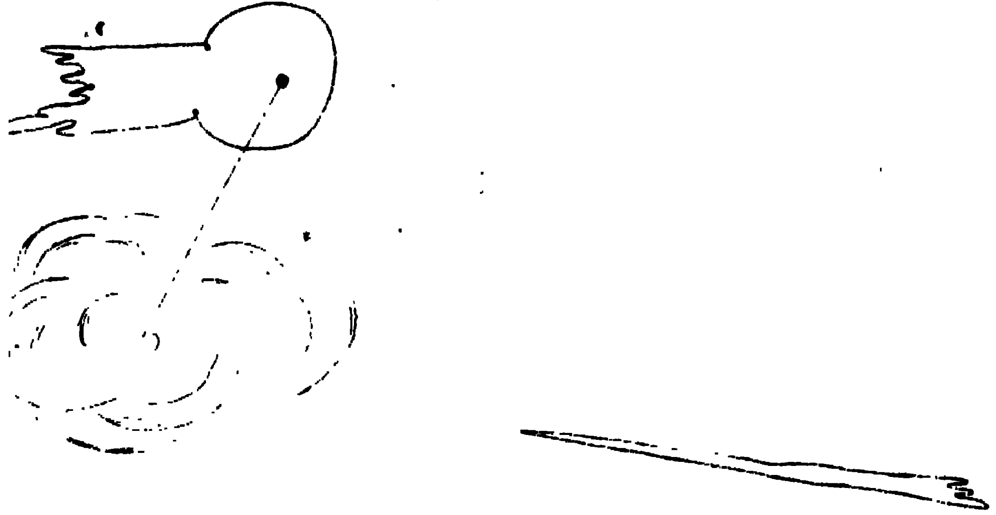
* See also Harris "on Thunder Storms," p. 178.—*Note by Dr. O'Shaughnessy.*

† Professors Faraday and Henry (of New Jersey,) Mr. Sturgeon, Mr. Martyn Roberts, the late Mr. James Prinsep, &c.—*Note by Dr. O'Shaughnessy.*

near each other in Vourla Bay. The *Powerful*, without a conductor, was struck; the *Asia*, which had conductors, escaped.

4th.—A tree, distant 52 feet from a conductor, was struck and shattered, while the conductor and house escaped, that is, "the lightning fell on a body having little or no attraction for it, and held out no invitation to it, in preference to one which did."—(*Harris, op. cit. No.* 182.) Mr. Harris then states that it is comparatively a rare occurrence for lightning to strike a conductor.*—(pp. 185-187.)

5th.—It is moreover advanced, on the authority of Franklin, Harris, and others, that pointed metallic bodies "exhaust the electricity of the clouds and cause them to shrink back," thus obviating the concentrated explosion, which otherwise would probably ensue by the extension of the general mass towards the earth. Experiments are accordingly adduced in which flocks of cotton suspended from the prime conductor of a machine recede on the approximation of a metallic point; and Mr.



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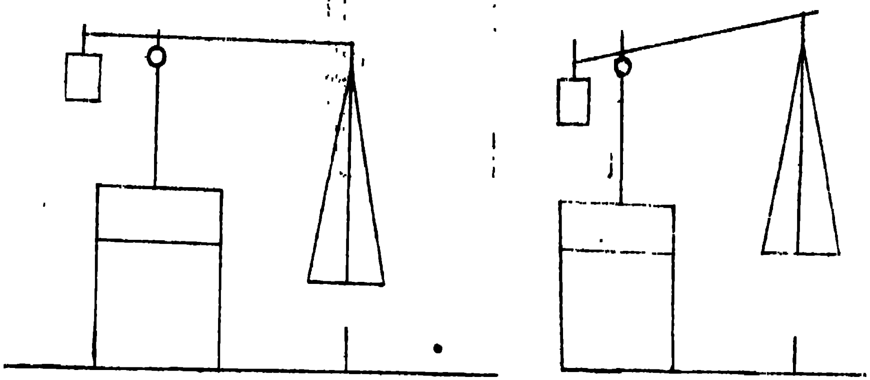
* Here is the passage alluded to:—"Before quitting the subject of the absolute protection from lightning afforded by conductors, the 'Naval Commission' enquire, whether, according to the common prejudice, conductors have the power of *attracting* a flash of lightning, which, in their absence, would not have occurred; and their report states, 'that the instances of accidents to ships *without conductors*, and the comparatively *rare occurrence* of lightning being observed to *strike* on a conductor, would tend to negative such a supposition.' They farther consider, from the instances which were submitted to them, of ships without conductors having been struck by lightning, in the presence of ships furnished with them, which were not so struck: that most complete evidence is afforded either of the little influence exerted by such conductors in inducing or attracting an explosive discharge, or of their efficacy in harmlessly and imperceptibly conveying away electricity to the water."—Ed.

Harris dwells emphatically on an experiment in which a balanced scale, from moving freely on the knob of a charged Leyden jar, was repelled, as it passed over a metallic point, connected with the outer coating of the jar—thus :



Lastly, the same writer states, that " lightning has seldom if ever been known to fall in an explosive form upon buildings involving pointed metallic conductors in their construction."

Such is a fair epitome of the evidence on which Messrs. Harris and Daniell deny that lightning conductors attract or determine discharges upon themselves. Let us examine the facts and arguments adduced in the order above given.

Professor Daniell states, that " the intense action which takes place between an electric cloud, of the extent perhaps of 1,000 acres, and an equal area of the earth's surface, is much too extensive, to be materially diverted by the mere point which can be erected on the latter, and which, as compared with the extent and distance of the charged clouds, must be quite inconsiderable."

On this I have to observe, that however great or distant the cloud, there is abundant evidence that intense action does take place between this cloud and pointed metallic bodies on the surface of the earth. Of this the following facts afford sufficient proof.

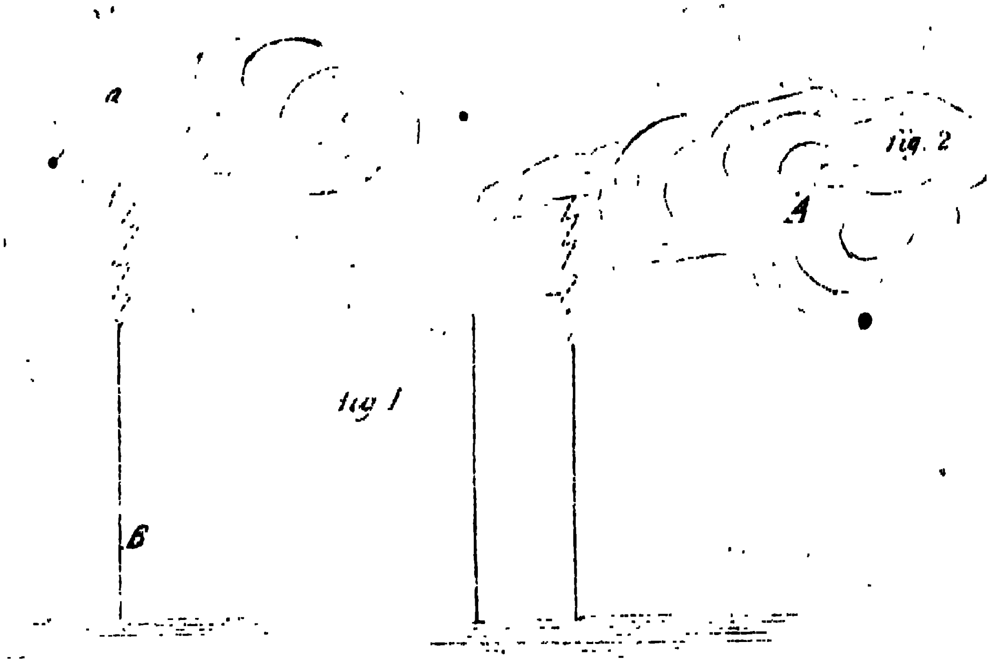
In the series of conductors which the illustrious Beccaria erected on the Royal Chateau of Turin, and in which a small interruption was designedly made for observation, on the approach of thunder-storms, a torrent of bright sparks always rushed through the intervals.

In the ever-memorable kite experiment of Franklin ; in its counterpart by Dalibard ; in those of Messrs. Sturgeon, Weekes and Barry in our own time ; in the death of Professor Richman of St. Petersburgh by lightning thus brought into his study ; in the tremendous lightning explosions with which Mr. Crosse terrifies his neighbourhood, and which he manages at his pleasure; we have ample, familiar, and irresistible proof that, between electric clouds and pointed metallic bodies on the earth, a powerful and reciprocal action takes place, an action capable of destroying life, of igniting and exploding inflammable bodies, of effecting in short all the disasters which it is the object of this enquiry to guard against; and yet this is what Mr. Daniell regards as too inconsiderable to be noticed.

But where this action *begins*, there its increase is determined. This is most important, and I quote the words of Faraday in its proof:—" The *commencement* of the act at any point favors its continuance and increase * * * portions of power will be discharged by a route which otherwise they would not have taken * * *. It is not the whole quantity that passes which determines the discharge, but merely the small portion of force which brings the deciding molecule up to its maximum tension; then, when its forces are subverted and discharge BEGINS, *all the rest passes by the same route."—Faraday's published correspondence, page* 26.

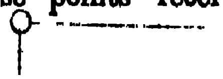
I have thus shown, that action of great energy takes place between conductors on the earth and clouds at ordinary elevation. Mr. Faraday's unquestionable authority shows, that where this action *begins*, the rest of the discharge tends to follow. Let us next recall to mind the phenomena of a tropical storm, with huge masses of electric cloud rolling along almost in contact with the earth, and involving our habitations in utter darkness, and we can scarcely agree with Mr. Daniell in his opinion that the action of the conductor is too insignificant to be regarded.

I pass to the second position of these gentlemen, namely, that " lightning often avoids pointed conductors and falls on adjacent objects," a statement which seems totally inconsistent with the idea that pointed conductors attract lightning upon themselves: nevertheless examination of the facts before us leads to a different result. Let us admit for a moment the existence of the disputed attractive power in the conductor; if it exists at all, it must, like other attractions, be influenced by favorable or counteracting circumstances. Thus the attraction of a horse-shoe magnet for a piece of iron is most powerful in the direction of the axis of each limb; but the power diminishes to nullity at a trifling angle from this line. Thus with the electric conductor. If placed vertically beneath an excited body, the reciprocal action takes place from an immensely greater distance than when they are placed in an angular position to each other. Let *A* (figure 1) be an excited cloud immediately above a conductor *B*, on which an explosive discharge passes, say from 1,000 feet distance. In figure 2, let *A* be a cloud approaching laterally; that the discharge will strike *C* at 1,000 feet sooner than *B*, at half that distance is rendered in the highest degree probable by the experiment subsequently detailed.

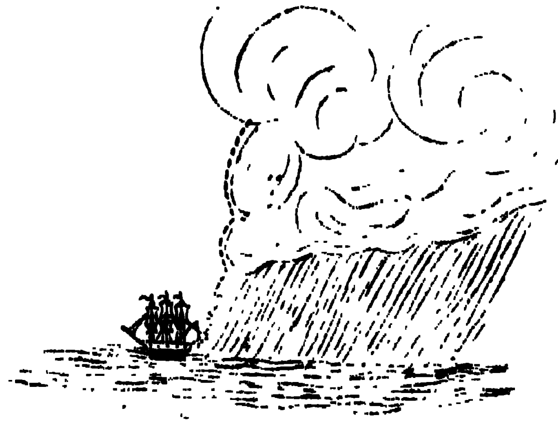


But a disturbing influence of far greater importance, both as regards this argument and its practical objects, exists in the action of *rain falling at the moment* of the discharge. To this action, I have to solicit the especial attention of all interested in this enquiry, as it explains satisfactorily nearly every difficulty with which the subject is apparently beset.

When rain is falling, there is at once established, between the cloud and the earth, a multitude of interrupted conductors. Every drop of rain serves as a link in a chain of direct communication. By the quantity and surface of the liquid shower, all other conductors are superseded in their action. This may be beautifully shown by experiment. Let the inner coating of a Leyden battery be discharged over a piece of wet tape (*t*); this may be passed through a circle of points in connexion with the outer coating without these points receiving or diverting the discharge.



In our tropical storms, we witness the same occurrence on a scale of indescribable grandeur and sublimity. As the clouds roll before the north-wester, who has not observed with admiration the lightning darting along the edges of the black masses of rain and vapour, embroidering them with borders of fire. Let us suppose a rain and thunder squall thus advancing to a ship, however well provided with conductors, and who can wonder that, great as may be their attractive power, the flash strikes the sea, guided by the cloud and falling rain, before the shower reaches the mast of the vessel.



I hold therefore, that in the instances of the ships named by Mr. Harris, before any conclusion can be derived from the occurrences in which they are concerned, whether in favor of, or adverse to, the existence of this attractive power, there are other circumstances than the mere distance between the vessels or other objects to be taken into consideration. These are, whether rain is falling at the time, and the direction of the wind is the guide of the rain. This is not specified in the cases before us, which are accordingly, in my opinion, inconclusive altogether as to the question now at issue.

But there are other disturbing causes, which may entirely counteract the agency of a conductor. There are many houses in India, one for instance of much notoriety at Midnapore, so frequently struck by lightning as to be occupied with constant apprehension, yet those houses are *apparently* situated, like many others, at the same stations. We cannot tell the inscrutable cause which guides the meteor upon these devoted dwellings; but their being struck, although in the neighbourhood of conductors, could not disprove that those possess attractive power.

With reference to the granite chimney in the Plymouth Yard, which was struck by lightning at a distance of 300 feet from the conductor of the clock tower, Mr. Harris omits to notice that the chimney being lined with soot, and in all probability filled with heated air and smoke, was itself an admirable conductor, one quite as likely to determine a discharge as an ordinary lightning rod. Is it not likely, too, that rain was falling at the time of the explosion?

Again, with reference to the tree which the same writer cites as having been struck by lightning within 50 feet of a conductor which escaped; the lightning "thus falling upon a body which had little or no attraction for it," I cannot but express my surprise that he should have overlooked the singularly beautiful experiments by Mr. Pine, recorded in *Sturgeon's Annals of Electricity* and in the *Proceedings of the Electrical Society of London.* From these experiments it is obvious that many pointed living plants are as conductors or dischargers of electricity quite equal in power to equal masses of metal, so that every argument which applies to conductors appertains to trees as well as to metallic rods.

Mr. Harris next states, that it is comparatively a rare occurrence for lightning to strike conductors; yet his own valuable work supplies numerous instances of such occurrences,* and in India it is such a common event as to excite but little observation.

I now arrive at perhaps the most serious argument which Mr. Harris has advanced, one based on Franklin's celebrated experiment on cotton flocks suspended by a thread from the prime conductor of a machine. On presenting a metallic point, the flocks were exhausted of their electricity, and then receded to the prime conductor, and a scale pan balanced on the knob of a Leyden phial was in the same manner apparently *repelled* by a point in one of Mr. Harris's experiments.

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* H. M. Ships *Ætna* and *Winchester*, the *New York Packet*, H. M. Ships *Dryad, Druid, Asia, Talbot, Actæon.* The *Heckingham Workhouse, Purfleet Magazine*, &c. &c.—*Note by Dr. O'Shaughnessy.*

Sir W. Snow Harris? Sir Wm. Harris, however, points out how thoroughly the conductors performed their duty in all the above instances, pages 170, 171, 172 and 173.—Ed.

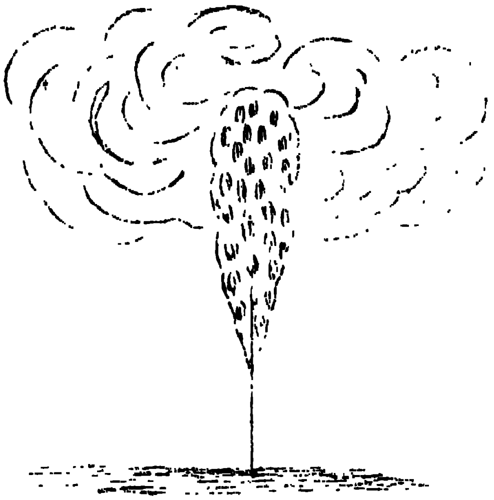
Were these experiments fair illustrations of what occurs in nature, we should be driven to conclude, not only that lightning rods have no attractive power, but that they actually *repel* the cloud. But attentive examination of the true indications of the experiment leads to a very different result.

The cotton flock is capable of receiving but a very *minute* electric charge, which an approximated point immediately draws off, when the flock is at once attracted with great force to the prime conductor of the machine, so that the apparent repulsion from the point is in reality the effect of the attraction of the machine.

But let us use any light body, say a balanced metal scale pan, capable of receiving a great charge of electricity, and thus supplied by a Leyden jar.

Let the pan be free to move horizontally and vertically, what is the result? The pan descends towards the point beneath it till the discharge begins to take place, and then rises, *being apparently repelled.* But close examination shows, that a rapid current of air is setting upwards from the metallic point, and it is this current of air impinging on the solid scale pan which forces it to recede.

Exactly the same effect is produced by a heated metallic point on an unelectrified scale. Thus the experiment so explained, and in a manner that no experimentalist can deny, proves literally nothing, either for or against Mr. Harris's opinions. But let us admit, that a similar current of air must flow from the point of a lightning rod upon the cloud with which it is in electrical relation, the influence of such a current would not move a feather at the height of a 100 feet, and even supposing it as powerful as a jet of high-pressure steam, and admitting it to reach the cloud, this being a body composed of independent molecules, each moveable without imparting motion to its fellow-particle, the current of air could merely open a space through the cloud equal to its own area of contact, and produce no mechanical effect whatever on the rest of the vapour.



It thus appears to me that the facts and arguments advanced by Professor Daniell and Mr. Harris are not sufficient to disprove the general belief that lightning rods can attract or determine explosions upon themselves, on the contrary, it seems obvious, that as metallic rods have the power of commencing the discharge; as this commencement induces the rest to follow in the same route; as numerous disturbing causes may interfere with this determination and thus disguise its existence; as pointed conductors are struck with a degree of frequency which seems impossible from their mechanical smallness, unless they possess attractive power; we have even already sufficient evidence to justify our old belief.

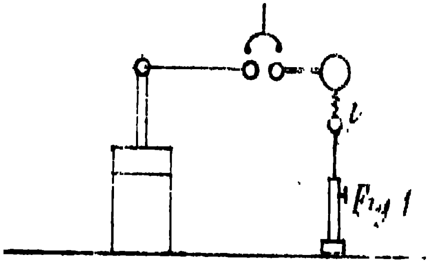
But as the question seemed one capable of decisive experimental illustration, several experiments were accordingly undertaken in the laboratories of the Royal Society of Dublin, of the College of Surgeons, and the London Polytechnic Institution, the results of which will, I trust, demonstrate that lightning conductors are not mere passive channels for electric discharges, but attract or determine these discharges upon themselves, expressions which I deem to be of the same signification.

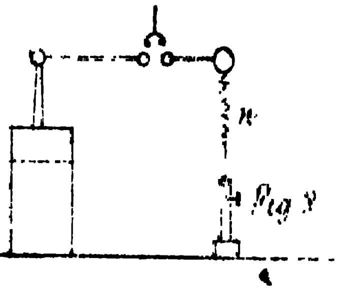
EXPERIMENTS.

The battery used consisted of 6 gallon jars, exposing in all 12 feet of coated surface, excited by a very powerful cylinder machine. The maximum charge the battery received was indicated by 25° of the quadrant electrometer.

A brass ball *A* was so arranged, that contact could be suddenly made by a discharger between this ball and the inner coating of the battery.

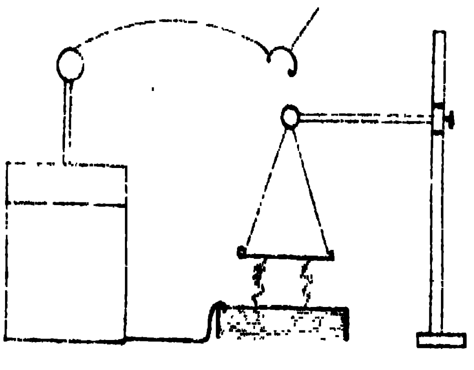
Beneath the ball *A* was adjusted a sliding brass rod in contact with the outer coating, which rod could be made to terminate at pleasure in a brass ball, (fig : 1,) or a steel needle, (fig : 2,) and the striking distance adjusted by a screw, in the stem of the sliding rod.

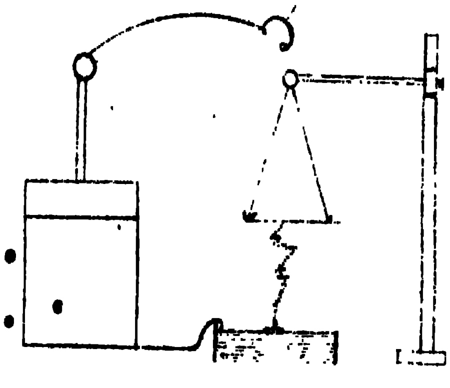




The battery being charged to 25° the striking distance to the ball *b* from *A* was found to be ¾ of an inch. The ball *b* was now removed, and the steel point *n* substituted, and the experiment repeated several times, increasing the distance each time. The result was that the striking distance to the point was rather more than doubled in comparison to that to the ball *b*.

To imitate exactly the case of ships at sea, the outer coating was connected with a trough filled with sea-water, over which a circular disk of copper was suspended from a stand by which its distance from the surface of the water could be adjusted. The striking distance to the water was ascertained by several experiments, and found to be rather more than an inch, with an electrometer charge of 25°. The discharge struck a different place almost every time. A cork float with a needle was now placed on the water, and the above experiment repeated. It was invariably found that the explosion fell every time upon the needle, and very nearly at double the distance it did to the *water* surface.





I submit that those experiments prove that a plane, spherical, metallic, or water surface, may be in perfect safety, that is, not liable to discharges of lightning from a cloud at a given distance, say 1,000 feet, while a pointed metallic conductor will certainly determine an explosion upon itself at double the distance above given, say 2,000 feet.

2nd.—That a solitary ship at sea, provided with conductors, will, in a thunderstorm, if no rain be falling, be struck at double the distance at which she would be liable to explosion without conductors.

3rd.—Consequently, as all other circumstances are alike, and the presence or absence of the pointed conductor the only difference in the above experiments and illustrations, it is to the presence of this conductor the discharge is due; that the discharge is caused by the mutual inductive action between the bar and the cloud; in fine, that this bar determines the explosion upon itself, or attracts the lightning which otherwise would either have remained undischarged or fallen on some other object.

The universal law of the equality of action and re-action renders it impossible to conceive, that a metallic bar should remain unexcited in the vicinity of an electric cloud, nor can we conceive the occurrence of an electric discharge, till the object receiving it on the earth's surface has become excited in due proportion to the state of excitement in the cloud. This being granted, how can we any longer regard the conductor as a passive channel, a thing on which the lightning falls by chance. The doctrine is fatal to the very uses to which its advocates suppose conductors are applicable. They either attract the discharge upon themselves, or they do not. If they do not, their use or value must be limited to the spot they occupy, a *reductio ad absurdum*, which the anti-attraction reasoners would scarcely stand by, and which may be thus fairly stated:—"No action takes place in the rod: it is entirely passive: its transverse sectional area is one superficial inch, and it is placed as a protector to an area of 20 feet by 30 feet or 600 superficial feet: the chances of the rod not being struck by lightning are as 86,400 to 1.

In very recent papers, there seems an admission, that there is attraction within short distances, but that this becomes insensible at a greater distance, and 60 feet appears to be the maximum amount of this concession. But all the facts combine to prove that the only limit of attraction is the distance at which induction commences, that is, at which an electric cloud causes a bar to show any manifestation of excitement.

It remains then to enquire, whether the visitations of lightning which we draw down by our conductors are free from, or fraught with, danger, especially to our Powder Magazines.

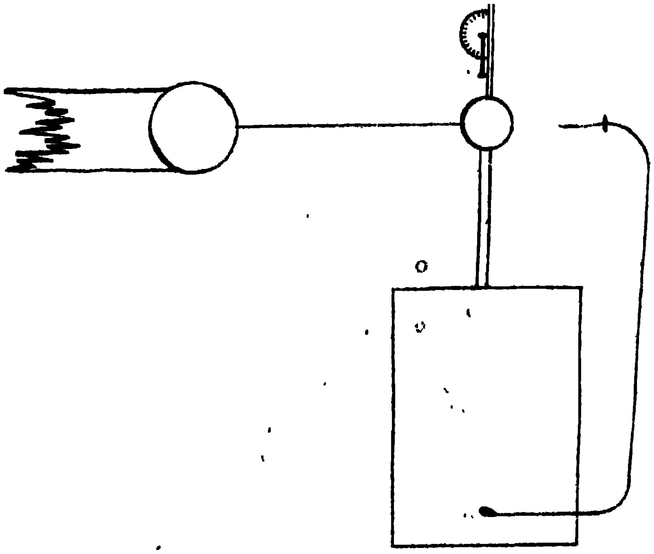
QUESTION 2ND.—*Are lightning conductors capable of exhausting silently the electricity of the clouds, so as to render them harmless, and thus avert explosions of lightning?*

There can be no doubt that, when electric clouds form slowly and when the quantity of electricity is moderate, well-constructed conductors may draw off in silence the entire of the electric matter they contain, and thus obviate all danger from lightning. Thus, in temperate latitudes, thunder-clouds have frequently been seen to disperse on approaching an electric kite or other good conductor.

But this salutary power is restricted within a very limited circle. Let the thunder-cloud approach *rapidly*, let its area be very great, let the quantity of electricity be of that prodigious amount we witness in Indian storms, and then the exhausting power of the metallic rod is indeed too insignificant to be seriously regarded as a means of averting explosive discharges.

A series of experiments were made with the machine and battery above described, to obtain some data on this point.

The outer coating of the battery terminated in a thick copper wire ending in a fine steel point, which was brought within 3 inches of the brass ball by which the battery was charged. To communicate the maximum charge of 25° with the needle at this distance required 2 minutes 40 seconds, being one-fifth longer than was requisite to charge the battery to the same amount when the conductor was away.



In this experiment, a circumstance occurs, which would mislead an inexperienced electrician. The index of the electrometer does not rise so long as the needle is presented, but on this being removed, it instantly springs up and indicates the charge received.

Assuming with Mr. Harris the identity of the relations of the thunder-cloud and earth with those of the inner and outer coatings of the Leyden battery, it appears from the above experiment, that the number of lightning rods usually provided for a mansion or public building in India can exercise but a very trivial force in diminishing the accumulation of electricity or in preventing disasters from its discharge.

For if one perfectly constructed conductor within 3 inches of the oppositely charged ball abstracts one-fifth of the electricity the inner coating receives from the machine, 5 such conductors would be required to prevent any accumulation in the same surface, *viz.*: 12 feet. Thus to prevent or exhaust all charge in a cloud of one superficial acre (a square of 70 yards each way) 18,150 conductors would be required.

QUESTIONS 3 & 4.—3. *In conveying discharges of lightning do the best constructed conductors invariably carry off, in a harmless state, all electric matter which falls upon them, or do they permit a portion of this matter to leave them and strike adjacent bodies?*

4. *When lightning conductors convey all the electric discharge to the earth, is the mere passage of this electricity capable of causing electric action in adjacent bodies and producing sparks between them?*

Although both those questions admit of brief, direct, and unequivocal replies in the affirmative, nevertheless the singular opinions advanced on this point by Mr. Harris compel me to discuss them at some length and to submit to the Military Board a statement of facts derived from experiment and from the examination of the effects actually produced by lightning, which must remove all doubts on the subject from every unprejudiced enquirer.

Let us first hear the opinions of the distinguished writers alluded to.

Prof: Daniell says—"No discharge will take place from a metallic conductor to any neighbouring body, unless it be insufficient in itself to conduct the whole of the discharge, or unless the body in its vicinity be a better conductor than itself."

Mr. Harris says (*Op. cit.* p. 195.)—"If lightning rods are liable to produce lateral explosions upon surrounding bodies, then there is not a

Powder Magazine in Europe armed with such rods which, upon being struck by lightning, would not either be blown up or damaged; but this at least we have shown has never been the case."

The melting of the conductor is considered by Mr. Daniell as the limit of its capacity for conveying away discharges of lightning; that is, unless the flash melts the conductor, this must be sufficient to carry it away in safety and to prevent lateral explosion.

Now numerous experiments and natural facts are recorded which prove directly that under many and common circumstances, electric sparks, or flashes, do occur from perfectly constructed conductors to metallic bodies in their vicinity. It is unimportant with reference to the real and grave objects of *this* enquiry to enter upon speculations as to the nature of those discharges; equally trivial is it to dispute about the name we should apply to them. It is the simple fact of their occurrence and the circumstances under which they take place which should seriously engage our attention.

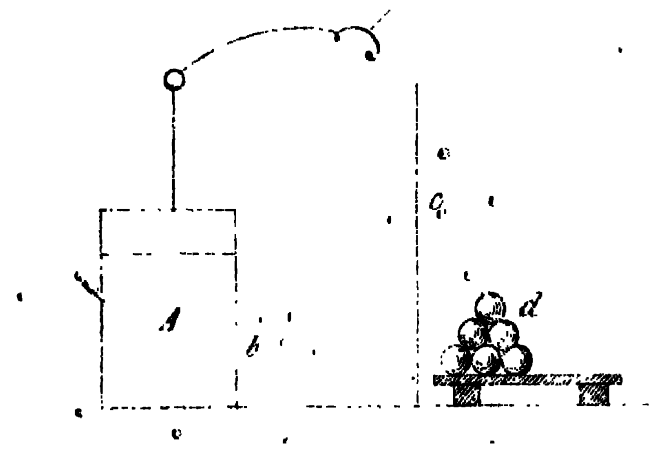
I proceed accordingly to specify the various kinds of flashes which experiment and experience prove the occurrence of during the transmission of lightning through well-constructed conductors, of such size, that they can carry off the heaviest explosions without fusion,—such flashes may be classified under two heads.

Those from the conductor itself to adjacent objects.

Those which occur among adjacent bodies without any explosion from the conductor itself.

EXPERIMENT.

Let *A* be a battery, *b* its outer coating, *c* a large brass conductor connected with *b* by metal and capable of transmitting without fusion the discharge of a battery of much greater size. If a metallic body *d*, such as a gun, a pile of shot, shells, copper, powder barrels, &c., be placed near *c* on the ground or on a boarded floor, at every discharge of the battery, a vivid spark will pass from *c* to *d*.



The larger the mass of metal at d and the greater the battery charge the larger and more vivid is this spark or flash; and even when produced by a single quart jar, it is capable of inflaming gunpowder, and will pass through a wooden partition one-third of an inch thick, leaving no trace of its passage on the wood. The shot or gun or other metallic mass may be connected with the ground or even by a long metallic circuit with the conductor, and still this flash will occur.

The fact now described is admitted by Mr. Faraday and also by Mr. Harris, but it is on its proper name that Mr. Harris concentrates his attention and turns the discussion. He says it is not to be designated " lateral flash ;" it should be called " division of charge." Mr. Faraday also prefers this name, and ascribes the occurrence to " resistance" in the bar. Mr. Daniell attributes it to a supposed and peculiar arrangement of the experiment in which the metal receiving this spark is placed so as to receive it not from the battery but the prime conductor of the machine. I have only to reply that I look upon the name of this flash as a matter of no importance whatever: as to Mr. Daniell's mode of explaining it, it is sufficient to observe that the machine in my experiments was entirely separated from the battery, and several feet away from it and from the conductor. The *fact* then is what we have to look to, and it constitutes the experimental proof of all I have ever contended for, namely, that " *lightning conductors as usually applied and however well constructed cannot prevent flashes proceeding from them to other adjacent bodies, especially if those be metallic, and although separated by wood, masonry, or other imperfect conductors.*"

I proceed to describe an instance of this occurrence in nature, sufficient in itself to prove all we contend for. It is the history of the accident which occurred by lightning to the magnificent cathedral of Strasburgh so lately as the 10th of July 1843. The account is condensed from the original paper by Mr. Fargeand, published in the *Comptes Rendus* of the French Institute of the 7th August 1843, No. 6, p. 254, and translated in the *Electrical Magazine*, p. 173.

The noble spire of this cathedral is the highest structure in the world, being 474 feet high, 24 feet loftier than the Pyramid of Cheops, 140 feet higher than St. Paul's in London. It is protected by a vertical iron bar two inches thick, pointed with platinum, placed on the summit of the spire. From this bar proceed four others, each two inches wide and half an inch thick. These descend the spire equi-distant from each other till they unite in a circle at the base of the tower and roof of the church. They are here united with the immense copper roof, and from the metallic circle three bars descend along the tower to wells 33 feet deep. Close to one of those wells, but separated from it by a passage six feet wide, is the back of a tin-man's shop. The well in the driest weather contains at least 3 feet of water. In those wells the conductors terminate in sharp copper bars. In short, all the metallic components of this unrivalled edifice are connected together with a system of conductors as perfectly arranged as profound science and architectural skill could dictate.

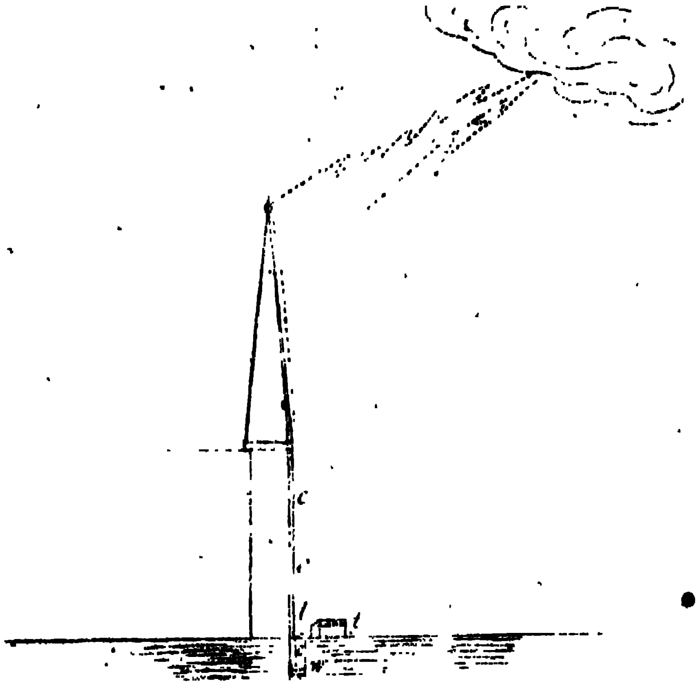
On Monday, the 10th July, 1843, a violent thunderstorm burst over Strasburgh, and the spire was twice struck by lightning, with an interval of but one minute between the flashes.

The watchman stationed at the telegraph on the tower, two-thirds of the way up the spire, saw a luminous train rushing along the conductor from the top of the spire to the platform which concealed its further course from his view. At this moment occurrences took place in the tin-man's shop, 6 feet from the next conductor, which deserve the closest examination.

There were seven or eight persons in the shop; a considerable number of tin and zinc vessels ranged along its sides and in the loft; there were long bars of iron resting against the wall of the shop in the corner next the conductor of the church. At the moment of the explosion all the persons present saw a flash of lightning which apparently entered by the door which opens on the place, passed between the legs of the persons in the shop, and burst in a great flame against the bars of iron placed against the wall. In barely one minute after the first explosion a second occurred with precisely the same result.

There is a passage 6 feet wide between the back of the tin-man's shop and the wall of the cathedral. In this passage, between the conductor and the rear of the shop was a heap of lead and copper weighing about two tons. Whether the lead touched the conductor or not is not known. The lead and copper were moreover close to the part of the wall of the tin-shop against which the iron bars were placed.

I give a coarse diagram of the spire and shop, and proceed to quote the important words of Mr. Fargeand, by whom the conductors had been erected eight years before.



(The dotted line in the diagram shows the places where the lightning was seen; *c c* the line of the conductor to the well *w*; *t* the tin-man's shop; *l* the heap of lead between the wall of this and the next conductor.)

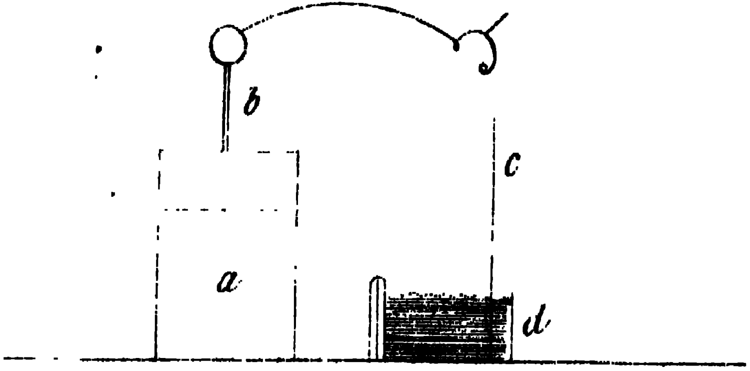
Mr. Fargeand says—"Very probably some of the sheets of lead touched the conductor; but it was impossible for us to verify the fact. On our arrival the workmen had already removed a considerable portion in order to clear the mouth of the well. Admitting this contact we see that this great surface of extraneous metal had the power of drawing off a portion of the current from its original direction and directing it towards the most vicinal exterior conductors. The masses of tin, zinc, and iron which crowded the work-shop and the loft above favored this deviation."

"If contact did not take place we must suppose that at the moment before the explosion, all the conductors vicinal to the lightning rod, but not connected with it, were electrized by induction. When the explosion occurred, a true return shock must have been produced in a locality previously prepared, so to speak, in the best possible manner for a phenomenon of this kind. Further, while attaching some degree of importance to the direction of the fluid, we need not trouble ourselves about the direction in which some persons say they saw it travel: we know how very easy it is to be deceived on this point."—*Vide* "*Electrical Magazine*," p. 173.

I earnestly pray that this event may be regarded in its proper light, as a demonstration of the calamities to which we expose ourselves by placing gunpowder or other explosive substances among masses of metal in the vicinity of ordinary conductors, however well constructed or applied. Had the tin-man's shop been a Powder Magazine containing powder barrels lined with copper, can there exist much doubt that it must have been exploded by those flashes although within 6 feet of a perfect conductor with a wall intervening? Whether the flashes seen in the shop came from or struck towards the conductor, whether we term them "subdivided," "lateral," "return," &c., the fact, the conclusive warning fact, that they occurred close to an admirable conductor, and were occasioned by this conductor is beyond all cavil and misinterpretation.

The incident, moreover, furnishes us with another valuable lesson; within the tower no such phenomena took place, because it was surrounded by metallic branches, within which no secondary flashes of any kind could occur. How this fact may be applied for the perfect protection of our Magazines will be shown in the sequel of this letter.

Under the head of direct flashes from conductors, I have next to consider one which has hitherto attracted no notice from the eminent writers who have recently discussed this subject; nevertheless, it is one of the highest practical importance, and likely to lead to most disastrous results. Its nature will be understood by reference to the annexed figure.



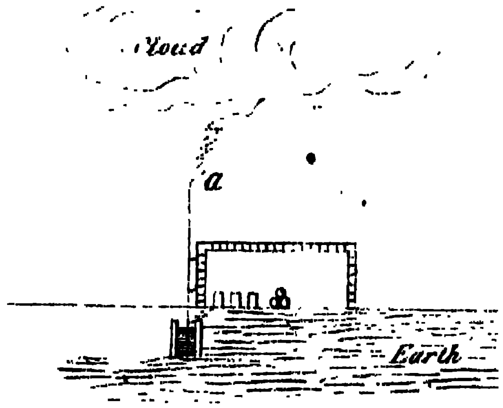
a, outer coating of battery, with thick copper wire, dipping into cistern of water *d*: *b*, inner coating discharging on conductor standing in the cistern.

On discharging *b* through *c* if the charge be 25° of quadrant electrometer, battery surface 12 feet, at each discharge a bright zig-zag flash passes with a loud explosion from *c* to *a* over the surface of the water.

The same occurs if the conductor be placed in a box of damp soil, and the more wet this be, the more effectually and certainly does the discharge pass along the surface of the soil.

Weak charges under 20° (quadrant electrometer,) or from surfaces much below 12 feet, pass silently through the water or soil only occasioning a mere faint spark and hissing sound.

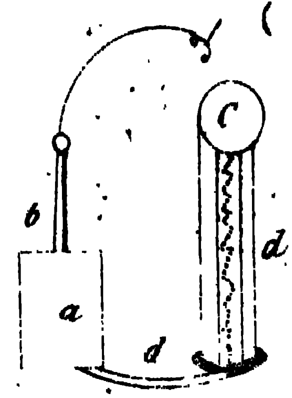
Let us apply this experiment to the case of a Powder Magazine with the usual conductors applied a foot from the wall and led into a well or simply inserted into the ground.



I do not entertain the least doubt but that a flash striking *a* would leave the conductor or sub-divide at the water level and strike at the powder barrels and shells in the Magazine. The case of the Strasburgh tin-shop sufficiently shows that the intervention of a wall is not a screen impenetrable to electric action.

The remarkable fact of lightning leaving the conductor as a flash on the surface of the water led the way to further experiments, the results of which are considered in some degree novel and important by the eminent men to whom I had the pleasure of exhibiting them in Dublin and London.

When lightning strikes a *dry* metal conductor, it ceases to be visible from the place it strikes, till it is lost in the earth, and while thus latent and invisible in the bar, this may be grasped in the hand and the most violent discharge be scarcely felt. But in the experiments I allude to, I found to my surprise that *if a discharge falls on a wet conductor*, it passes on the surface as a zig-zag explosive flash.



a—outer coating.
b—inner ditto.
c—large brass ball on a glass jar.
d—a strip of tin-foil.

When the tin-foil is *dry*, the explosion is absorbed at the ball *c* and is seen no further; when the tin-foil is wet, the explosion runs along its surface as a bright zig-zag flash.

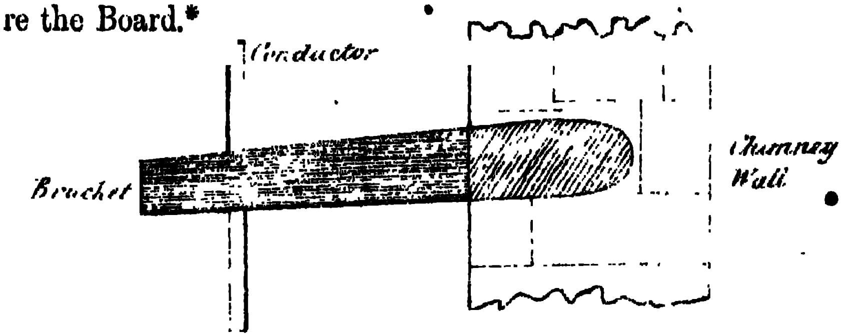
Mr. Harris, adverting to the luminous appearances sometimes noticed on conductors, gives his opinion that "it is a sort of glow of a perfectly harmless nature, and may be classed with the phosphorescent flashes attendant on the aurora borealis, or with the streaming of ordinary electricity in the receiver of an air-pump," (page 191.) It was easy to disprove this opinion and to show that this flash is not mere phosphorescence but the actual explosive discharge. By placing the tin-foil horizontally and sprinkling its surface with detonating powder, while the metal was *dry*, this powder was unaffected by the discharge; but when the tin-foil was moistened and then sprinkled with the powder, this was exploded at every discharge.

These experiments were repeated until we brought them entirely under control and showed them at pleasure. The applications of the fact seem to me to be of no little interest.

It explains the popular statements so often made, and denied by electricians generally, of lightning being seen to descend conductors, to play on iron roofs, to run down ship masts, to follow the track of railways, &c.

It lends support to the much ridiculed belief, that it is the surface not the transverse sectional area of a conductor which lightning discharges pursue. It exhibits in the most unequivocal light the objectionable character of the conductors which Mr. Harris has induced the Admiralty to inlay in the lower masts of our men-of-war, leading them through the ship's hull to the kelson and thence to the copper sheathing. Mr. Harris convinced himself and the Admiralty that this plan was safe by experiments he performed on *dry* conductors led through loose gunpowder and which conveyed discharges with safety. Had he used *wet* conductors, like those of a ship while rain is falling, and had he employed a sufficiently large battery, he would have obtained very different results.

A natural illustration of my statement occurred this year, at the Government Iron Bridge Works at Alipore. The chimney is provided with a conductor most carefully constructed, and standing at about a foot distance from the chimney, supported by teak brackets. The conductor was struck by lightning during a heavy shower, and the whole of the brackets were reduced to masses of black charcoal by the lightning. Official details of this remarkable occurrence are doubtless already before the Board.*



Reverting to Mr. Harris's ship conductors, it happens fortunately that the Powder Magazines of our men-of-war are perfectly lightning proof, independently, or indeed despite of Mr. Harris's conductors. *They are all lined with copper*, and within this it is not possible that any explosion can penetrate. This very important fact is passed over in perfect silence by Mr. Harris; and is especially overlooked, when he argues with much triumph that no ship provided with his conductors has ever been blown up by lightning. I gladly bear testimony to the value of his inlaid conductors, for the protection of the spars and crew as far down as the caps of the lower masts; thence the system of inlaid metal should be discontinued and a path opened for the electric fluid by wire ropes led along the standing rigging, over the ships' sides to the chains and bolted to the copper sheathing.

Indeed the dictates of common prudence have recently induced the Admiralty to sanction this very important modification of Harris's conductors, and accordingly the *Queen*, of 120 guns, which I lately visited in Malta, has wire rope conductors led from the caps of the lower masts over the ship's sides and secured to the copper externally as above described.

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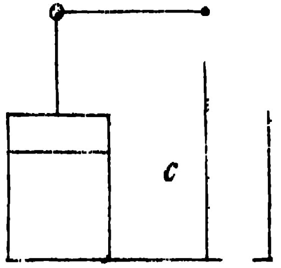
[1] No record of this accident can be traced.—Ed.

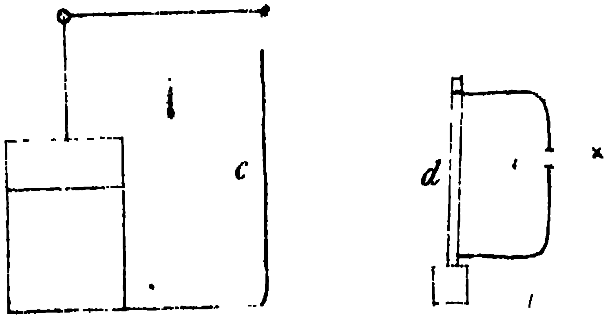
2. *Of sparks or flashes which occur among metallic bodies near a conductor conveying an electric discharge without any direct explosive communication between the conductor and those bodies.*

There are at least three cases in which metallic bodies in the vicinity of a conductor transmitting a discharge are likely to emit sparks or flashes capable of igniting gunpowder and other very inflammable substances.

A conductor cannot transmit a discharge, however feeble, without disturbing the electric state of all adjacent conducting bodies, thus at each discharge through *c*, *d* is affected.

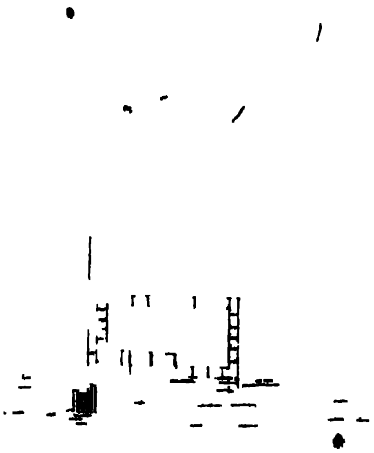


This is proved, by leading wires from each end of *d* so as to terminate near each other at + In this interval a bright spark is seen at every discharge through the conductor.

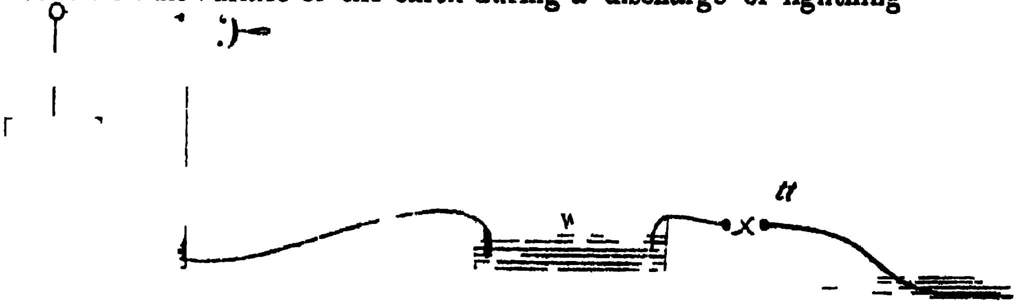


With a battery of but one foot of surface this induced secondary discharge occurs in *d* at a distance of 4 inches from *c*. It takes place when the bars are separated by wood, porcelain, or glass. It will not occur if the bars be at right angles to each other; but it is seen at all angles less than 45°. It requires but two inches of each bar to be in the same line. The spark ignites gunpowder. A large metallic screen between *c* and *d* prevents the occurrence of the spark. These beautiful experiments are due to Professor Henry, of Princeton, New Jersey, and were published in 1839. In June 1843, on a visit to Princeton, I had the pleasure of meeting Professor Henry, who then showed me an arrangement of extreme simplicity by which these secondary effects are produced when two wires are at over two hundred yards distance, and another, by which every flash of lightning which passes in a distant thunder-storm magnetizes needles in his study by the induction of this secondary discharge.

As to the nature of those sparks Professor Henry says:—"The sparks in the two last experiments are evidently due to the action known in ordinary electricity by the name of the lateral discharge." *(Transact. of the American Phil. Soc. vol. 8.)* Extending Professor Henry's experiments, it is found that a series of metallic bodies placed side by side give sparks to each other under the influence of this inductive excitement; applying this case to Powder Magazines, it seems obvious that sparks are liable to occur between the copper linings of the powder barrels, thus—



I shall trouble the Board with but one instance more of sparks of this kind; but it is one of importance, as it illustrates very closely what occurs on the surface of the earth during a discharge of lightning



Let w be a water vessel placed at a considerable distance from the battery, but having a metallic communication with the conductor; and $t\ t$ be metallic bodies adjacent to each other and one communicating with the water. At every discharge at the battery there is a vivid spark at $t\ t$; there may be several alternations of water in communication with the outer surface, and between all these and adjacent metallic bodies sparks occur at every primary discharge; we have here again every condition for the occurrence of flashes between the powder barrels, on the passage of a lightning discharge on a conductor outside the Magazine.

I have thus enumerated several cases in which a conductor conveying a discharge is likely to cause the explosion of gunpowder placed in its vicinity. Experiment establishes that in every one of those cases, the secondary flashes are increased by the proximity of the conductor and the quantity of the primary or lightning discharge. Thus far we have had to deal with facts and experiments, simple, decisive, and undeniable, but I have still to meet the statement of the eminent writer so often quoted, by which he maintains that all such facts and experiments are set aside. Were these thus applicable, he contends that every ship and every Powder Magazine supplied by conductors must, if struck, have been exploded by lightning, which experience has shown not to have been the case.

I have already explained the cause of this escape in the case of ships of war, the magazines of which are *lined with copper.* As to Magazines on shore, it is not to temperate but to tropical countries we should look for decisive facts. For forty years and more have our Magazines in India been unprovided with conductors, and none have been exploded, although in a single season exposed to at least six-fold the number of storms which occur in London, Paris, Leyden, St. Petersburgh, Athens,* &c., and each of our Indian storms in the mean number of discharges surpasses at least ten fold the mean of the storms in northern countries; yet in this long period but two buildings, (and those not Magazines); one an Ordnance Laboratory at Dum-Dum, one a Corninghouse at the Powder Works at Mazagon, have been blown up by lightning. But those houses were not Magazines; the powder was loose, and they contained numerous irregularly shaped metallic masses.

Many of the Magazines in Europe, again, have their conductors placed at a considerable distance from the building. I may mention that the Pigeon House Arsenal in Dublin Bay, which has one conductor on a mast at a distance which I should estimate at about ten feet; and the Magazine at Rome, close to the English Burial Ground, which has four conductors, supported by masonry pillars at a distance which I should reckon as about sixteen feet, which was also the estimate of the sergeant of the Artillery Guard on duty at the building.

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* See "Arago" Surle Tonnerre, p. 412.

The copper linings, now so generally used for powder barrels, are a great security in themselves; and if powder dust could be excluded, and the mechanical effects of lightning on the walls obviated, it would be quite sufficient protection against all the dangers we have specified.

For these reasons I look upon Mr. Harris's argument founded on experience as inconclusive. Had he the evidence of forty years in Bengal, with our numerous Magazines provided with ordinary conductors, I believe the result would be very different, and that it would present an awful list of calamities rashly provoked by over confidence in the indications of a still infant science, one daily and hourly enriched by the contributions of discovery or the rectifications of error, one which it is presumptuous to regard as an exhausted field in any one of the numerous departments it opens to investigation.

As far then as we have proceeded with this enquiry it appears that by the erection of ordinary conductors, we multiply the chances of visitations of lightning, and that these visits are prolific of danger to our Magazines. It now only remains to enquire, whether there exists any means of infallible protection by which these repositories can be guarded against the risk, to which, if unarmed, they are exposed in common with every equal area of the earth's surface.

QUESTION 5TH.—*Do we possess any means by which we may afford infallible protection to Powder Magazines against lightning explosions?*

Notwithstanding the conclusions thus arrived at, it is consolatory to reflect that the means of ensuring safety are still obviously within our reach.

It is well known that we may discharge the most powerful batteries on a metal powder flask without the slightest danger to its contents; shells of the thinnest copper charged with percussion powder may be placed with equal safety in the circuit of the most violent artificial explosions. It is impossible to kill a bird in a wire cage by the electric fluid; even wetting the skin, as in Franklin's amusing experiment with a wet rat, causes the discharge to pass harmlessly away.

Within such envelopes* of conducting materials no "sub-divisions of charge" lateral or return discharges can take place, all inductive influence being destroyed. It is accordingly thus that our powder should be protected.

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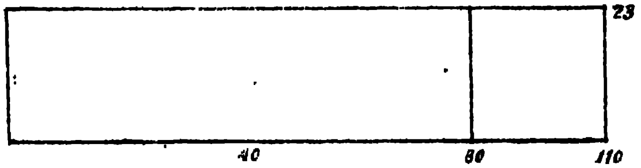
* A man in armour would certainly be safe in a thunder storm, from the great conducting power of the metal as compared with the human body.—*Harris on Thunder Storms*, page 95.—ED.

In my first letter on this subject, I recommended the construction, around each Magazine, of a series of iron conductors placed ten feet apart, and connected by lateral bands of iron or copper with each other. But the facts since accumulated, regarding the power of rain in directing lightning flashes close by the best conductors, show that not even on this system, still less on the old method, can we place absolute reliance.

Expense is the only objection which can be urged against the obvious mode of protecting Magazines, by enveloping them altogether in metallic sheathing. The subjoined plan, while equally efficient, will reduce the expense to a fair practical amount; it will guarantee security, and is applicable without causing alterations in our present Magazines.

Let us imitate the bird-cage experiment on a large scale, and take for instance the Cawnpore Magazine, the dimensions of which are 110 feet long, 72 feet broad, 23 feet high, by scale thus:—

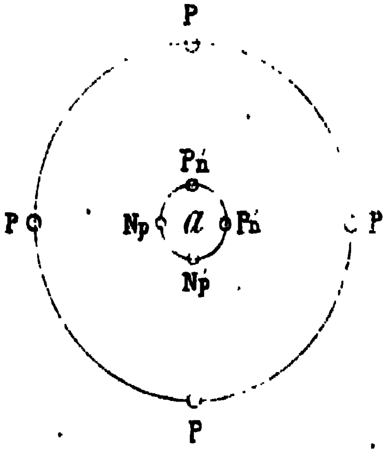


At every six or ten feet almost of the length I would attach to the wall and carry over the roof down to the ground, (at both sides,) a copper strap two inches wide; these straps would all be in the vertical line. A similar band should run horizontally along the roof, and have parallel bands at every six feet: assuming the curve of the roof to be a semi-circle, this would require seven such bands. At the level of the ground again a similar horizontal band should run. All the intersections should be rivetted or soldered together. From each corner I would further lead a copper rod with branches some feet into the ground. The whole arrangement may be thus represented:—The whole would require 33 maunds of copper, at 35 Rupees, value Company's Rupees 1,155, including rivets and workmanship, say Company's Rupees 1,500.

Hoop iron might be used; but its liability to corrosion by rust would be a serious objection. Rod iron might also be used; but I apprehend the joinings of the rods would present some practical difficulties.

I should observe that the *mass* of the copper above recommended, is much greater than that employed in Mr. Harris's ship conductors, which are also of sheet copper. I mention this to show that I am not depending on *surface* alone.

Within a Magazine thus arranged, it is impossible, according to the present state of our knowledge, that an accident from lightning can occur. The system can provoke no discharge upon itself; but will be ready to convey it when it may fall, and by distributing it equally in all directions, it obviates the possibility of any inductive secondary action within the building. For instance, no decomposition of the natural electricities of the globe *a* can occur, while *Pp are* conveying a discharge, as each *Pp* being positive tends to excite the negative state in the adjacent *Nn* and the positive in the opposite hemisphere *P'p'* of the globe. Thus every opposite pair *(P'p)* are equal antagonists, and neutralize each other's effects.



I beg permission now to add a few words regarding the protection of *ordinary public edifices and private dwellings.*

The objections to the use of ordinary conductors, which I have urged so frequently and emphatically in the case of Powder Magazines, are not so applicable to ordinary buildings within which an amount of electric disturbance may be permitted with safety, which would infallibly explode a magazine.

So far from deprecating the use of conductors, as Mr. Harris has supposed and stated that I have done, I have always urged their use for common buildings; but I wish their numbers to be increased; I would have at least *four* to each dwelling and have them all united at top by metallic rods.

To timid persons it may be some consolation to know, that at a trifling expense one apartment of a house may be rendered a *safety chamber*, within which no accident can occur. Let a copper strap one inch broad be run along the cornice; from this at each corner and at every six feet interval let a similar strap descend to the floor; along this let all be united with another horizontal strap; along every second or third beam let a strap run to the cornice; all should be rivetted at the intersections or joinings. From all the system at the level of the floor let a band or rod of copper be led through the wall and joined to the external conductor. Within this arrangement no accident can occur.

These straps may be painted to the colour of the apartment, others entirely concealed. The expense for an ordinary room need not exceed one hundred Rupees.

A bedstead may be effectively protected by a copper strap round its cornice descending each post, joined below, and one branch resting by the foot of the bed on a strap let into the floor and then running through the wall to a conductor outside. The most nervous person may smile at the lightning while reposing on such a couch.

From the whole of the preceding arguments it must be obvious to the Board that with Captains Pillans, Fraser and Weller, I regard the Cawnpore Magazine to be less exposed to risk without conductors than if armed with them on the ordinary method and in the common number.

But there is still the equal risk to which this Magazine is exposed in common with every equal surface, and I earnestly trust that to obviate this danger and guard effectually against the calamities it may lead to, the Board will adopt the simple and certain plan I have recommended, by which the Magazine will be placed in a condition in which, were it to be struck by lightning daily, still no disaster could ensue.

But it is at the same time my imperative duty to remind the Board that Messrs. Faraday, Daniell and Harris still regard the common system of conductors sufficient to afford the protection desired. Mr. Faraday fully admits nearly all the facts brought forward in this paper; but he still deems the use even of a single conductor to be immeasureably preferable to the leaving a Magazine entirely unarmed. Impressed with the deepest respect for Mr. Faraday's opinions, I differ from them with such self distrust, that I am naturally most unwilling to accept the sole responsibility of recommending a course in any degree opposed to his advice.

I therefore venture to suggest that the Military Board may be pleased to nominate a Committee of Engineer and Artillery Officers at the Presidency to enquire into the facts and views I have advanced, and report thereon to the Board. A steam electrifying machine with a large battery are now on the way from England for my use, and I expect them in October at latest. With this machine I can exhibit all the facts described for the satisfaction of the Committee, or make such further experiments as its Members might suggest for the elucidation of any obscure or doubtful point. The Board and the community would thus have the unbiassed opinions of a body of scientific Officers, experienced, moreover, in the phenomena of tropical thunder-storms to guide them in their decision upon references of such vital importance to the public safety.

W. B. O'SHAUGHNESSY, M. D. F. R. S.

No. 15.

PROFESSOR FARADAY'S LETTER TO MR. SECRETARY MELVILL, BEING A REPLY TO DR. O'SHAUGHNESSY'S 3RD REPORT.

Royal Institution, 7th June, 1845.

SIR,

I HAVE received your note of the 30th May, 1845, accompanied by the following Papers.

* * * * * * * * * * * * *

Your object is that I should furnish you with a Report of my opinion on the views and sentiments which have "been expressed on the subject in India as contained in the collection."

In reply I will quote the exact words of my former Report, *i. e.* the one referred to above, and contained in the papers you have now sent me, for "these with the other papers I have carefully considered, and as the general result beg to say I see no reason to alter a word of my former Report."

"In saying so much perhaps I say every thing that the Honorable Court of Directors desire of me, for it is probably more the *judgment* of the individual than the *reasons for the judgment that is required.* The latter is almost impossible for any man to give fully in a case where there are arguments and reasons on both sides of the question; for the bearings of these become almost infinite in number, by reason of the variation in the degree of force which they possess under varying circumstances, and at last it is the discretion, experience, tact, and caution of the person, which gives to his opinion any worth it may in reality possess."

The copy of my Report of the *9th June*, 1841, I will beg you again to read as if it were now an original document. I have paged it in red ink and corrected the references, and I have lined nearly the whole of it down the side with red ink* and the present date of 7th June, 1845. Every part so marked I present to you *now* as the results of my deliberate consideration and cautious judgment, and I have nothing at all to alter of the conclusions therein drawn; and therefore I will ask you to accept that Report, in conjunction with the sentence I am writing, as the expression of my opinion on the views and sentiments contained in the collection of papers you have sent me.

My Report contains an account of certain experiments on the division of a charge and the production of what is often called the lateral spark, the cause of which and the consequences that flow from it I have stated in general terms. On the other hand Dr. O'Shaughnessy, in the papers you have just sent me,† whilst objecting to the kind of lightning protector which I and the late Professor Daniell recommended, has himself advised another which, both in principle and practice, he considers absolutely safe. I would have avoided if possible, for the reasons expressed in my former Report, commenting on this plan; but as the very experiments I have just referred to show that the proposition cannot fulfil the expectation of the proposer, and that it might place the Magazines in much greater danger than the plan I approved of, and as you call on me for an opinion in continuation, I feel that I cannot, in justice to the Hon'ble Board, refrain from drawing its attention to certain points in the proposed arrangement and its effects.

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* See Professor Faraday's reply to Dr. O'Shaughnessy's Second Report, pages 44—52, the whole of which is so marked with the exception of 4th para. from top of page 45, 2nd para. page 50, and last sentence of page 52.—Ed.

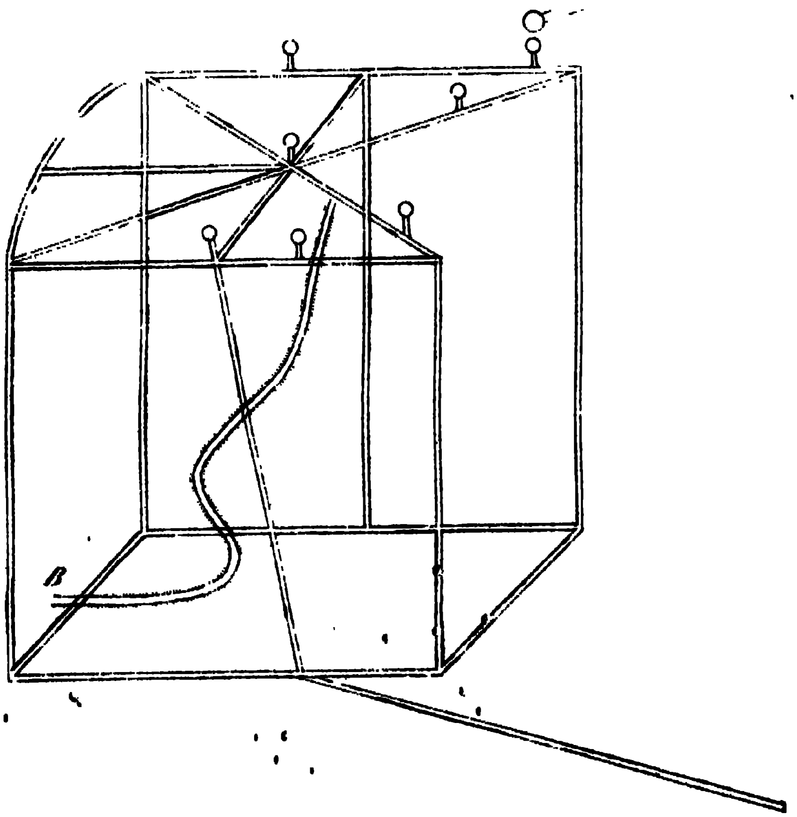
† Letter dated 24th August 1844.

It is said by the proposer that the most powerful batteries may be discharged harmless "on a metal powder flask without the slightest danger to its contents;" that "shells of the thinnest copper charged with percussion powder may be placed with equal safety in the current of the most violent artificial explosions;" that "it is impossible to kill a bird in a wire cage by the electric fluid;" that "within such envelopes of conducting materials no *sub-division of charge* can take place, all inductive influence being destroyed;" and, "it is accordingly thus that our powder should be protected."

There is evidently here and a little further on, the confusion of two distinct series of electrical effects essentially different, namely, the *static* and the *dynamic*; and it is no doubt this confusion which leads to the erroneous practical result which the proposer arrives at. He then states, and truly, that expense is the only objection which can be urged against the obvious mode of protecting magazines by enveloping them altogether in metallic sheathing; but immediately after says—"The subjoined plan, while equally efficient, will reduce the expense to a fair practical amount and will *guarantee security.*" The plan is then proposed of carrying a copper strap upwards from the ground against one side of a Magazine, leading it over the top and down to the ground on the other side; this is to be done at every six or ten feet of distance; similar bands are to run at intervals of six feet along the roof and across the former bands, being fastened to them by rivetting or soldering; a similar band is to run round the bottom of the building at the level of the ground and connect all the ends together; and lastly, from each corner of the building copper rods with branches are to go into the ground. The copper straps or bands are to be *two* inches wide; but their thickness is not given. However, it is said that hoop iron might be used if it were not liable to rust, and it is also said that the mass of the copper, (whether of each strap or of all the vertical straps is not expressed), is much greater than that employed in Mr. Harris's ship conductors.

It is then said—" Within a Magazine thus arranged it is impossible, *according to the present state of* OUR *knowledge,* that an accident from lightning can occur. The system can provoke no discharge upon itself, &c. ;" and then the philosophy of static effect, *i. e.*, of quiescent electricity, and not of discharge which, when it occurs, is dynamic in its character, is referred to.

I had no doubt from the results described in my former Report and now recalled to your attention that such a system as that proposed would easily give lateral sparks within, and that also under circumstances very similar to those likely to happen with a Powder Magazine. But to make it more evident to the Hon'ble Board I arranged a system of copper wires exactly in the manner proposed, so as to form a metallic cage (as in the figure below), of which the intervals between the vertical wires were only from 18 to 22, 30 and 48 inches instead of six feet or 72 inches, and the vertical interval no more than 57 inches. The wires were from $\frac{1}{12}$th to $\frac{1}{16}$th of an inch in diameter, well connected together, and finally, for the sake of a perfect discharge, connected by a thick wire of copper to the London water pipes.



Being thus arranged an electrical machine was set in action so as to throw simple sparks (without any Leyden jar) from the conductor, by a jointed rod, on to any part of the top of the frame, as for instance where the balls are represented. The sparks were not more than one inch and six-tenths long, and the wire of the frame or any single wire was sufficient to carry several hundred thousand times this quantity at one discharge without in the least suffering from it. Yet when a wire was connected with the lower rim as at *B*, or otherwise well connected with the earth as by the pipes, and being taken up *inside* the frame, was brought near the under part of any of the upper wires, a spark passed between that wire and the frame, at the occurrence of every spark from the machine. Nay more, whatever part of the lower edge of the frame this wire was made fast to, its upper end could take a spark from any place of the upper part of the frame at every spark from the machine. Still more, if the wire represented by the dotted line was only held near the frame at its top and bottom ends, then a spark from the machine on the top of the frame caused *two* sparks on the experimental wire, one at each end. If instead of one experimental or inner wire, two, three, four, or more were used, being connected below with the bottom of the frame, or with the water pipes, then *one* spark from the machine could produce a secondary spark on each of these wires, *i. e. four* internal or lateral discharges could be produced at different places within by *one* external spark.

I covered a part of the top of the wire-frame with sheets of wire gauze, the wires being only ⅛th of an inch apart, and therefore far closer than the wires of a bird cage, and I could produce the lateral discharge as easily from the inner surface of this gauze as from the former wires of the frame. I hung a cylinder of wire gauze *inside* the frame, and then had abundant lateral or secondary sparks from the inside of the cylinder. I took a large strong copper pan, 20 inches in diameter, and turning it upside down upon the frame, made it a metallic dome; when the machine discharged a small spark only on to it, or any part of the wire-frame, a lateral spark could be obtained with the utmost facility from any part of the inside.

My model was only about five feet high, but the Powder Magazine is 23 feet in height, and increases in distance from the place where the electricity strikes to the place of discharge (*i. e.* the earth) tends to render the effect more striking. I had only wires of copper instead of copper bands or iron hook; but my wires were far larger in proportion to the electric spark which I used than the bands of copper (judging from the weight given) or iron would be to the lightning flash. Such a system of bands, because of its infinitely better conducting power than stone or brick even when the latter is *wet, will tend* to make the lightning strike upon a Magazine which, without the bands, might not have been struck; and, considering the metallic nature of the contents of a magazine, that each powder barrel is lined with copper and that these and shells are often piled on each other from the ground upwards towards the roof, so as even sometimes to touch it, I think it very probable that a strong flash of lightning, striking the proposed frame-work, might divide after the manner of a lateral spark, as in the experiments described, and part of it take its course through the contents of the Magazine and thus cause its entire destruction.

In order to show that mere surface has nothing at all to do with these or any dynamic effects of electricity, I constructed a similar frame with *copper bands, nearly two inches wide*, and obtained the lateral sparks just as easily on the inside surface of these bands as with the wires. It could not be otherwise after the results of the experiment described with the wire gauze and the copper pan.

I have no doubt that if the Magazine were entirely enclosed in a case of copper and *that* copper were thick enough to conduct most freely the electric fluid, it would be protected; but I doubt whether a cage of copper straps such as those proposed would be sufficient to remove entirely the effects I speak of, even though the straps were so near each other as to leave no space exposed larger than a square foot; further, supposing that these straps were in some places to come apart, or else over lie, not being in actual or soldered metallic contact, there would almost certainly be a spark at each of these places when the lightning fell upon any part of the frame.

I have paged in ink the copy of Dr. O'Shaughnessy's letter or report of the 24th August 1844, which you have sent me and which I return with this paper of mine. You will find that from pages 37 to 64 it speaks of the power of a lightning conductor through which a discharge is passing, to effect neighbouring bodies and cause sparks to pass between them, and it gives many cases of the production of such sparks, as at pages 41,43—to and including 49 being the Strasburgh Cathedral, also 52, 53, 59, 60 and 63, and these are considered as reason against such a lightning conductor as I have recommended *now;* all these effects (being dynamic) take place as easily *within* the frame-work of straps proposed, as they do near a lightning rod, and upon exactly the same principles. They are *within* that frame-work just as surely " increased by the proximity of the conductor" (*i. e.* the straps) "and the quantity of the primary or lightning discharge," (page 64,) as they are in any other condition of the lightning conductor; and because the frame is in much closer approximation to the contents of the Magazine than the rod I recommend, are more productive of danger to these contents.

For these and all the reasons formerly and again adduced, my conclusion is the same as before, namely, that the conductor should not be put in contact with the Magazine; but as I have said in the close of my last Report, to which I again beg to refer you, should be about three feet distance from it.

W. FARADAY.

No. 16.

PROFESSOR WHEATSTONE'S LETTER TO MR. SECRETARY MELVILL, BEING A REPLY TO DR. O'SHAUGHNESSY'S THIRD REPORT.

King's College, 8th August 1845.

SIR,—In compliance with the request of the Political and Military Committee, that I should furnish the Court with a Report of my opinion on the views and sentiments which have been expressed in the correspondence submitted to me on the subject of the application of lightning conductors to Powder Magazines in India, I beg leave to make the following observations:—

The enquiry appears to me to resolve itself into two questions, which may be considered as totally distinct:

1st.—*Whether Powder Magazines are safer with, or without, lightning conductors, constructed according to the recommendations of Professors Faraday and Daniell, in their former Reports: and,*

2ndly.—*Whether the plan proposed by Dr. O'Shaughnessy is free from the defects which he and other gentlemen attribute to the ordinary method of protecting buildings from lightning.*

With respect to the first question, the subject has been already so fully and ably discussed as to leave no argument of importance to be brought forward in support of either opinion. My own conviction, founded, both on my previous knowledge of the subject and on an attentive perusal of the reports now submitted to me, is that Powder Magazines, like all other buildings, will be more secure from the destructive effects of lightning by the application of properly constructed conductors, by which I mean such as are recommended in the reports of Professors Faraday and Daniell, than if they be deprived of such protection.

As an argument against the establishment of lightning conductors, it has been urged that they are capable of determining a discharge which would not take place were they away, and that by thus "bringing" the lightning into the vicinity of the building, they endanger it when otherwise it would be safe.

To this it may be answered: the power which a conductor has of determining a discharge is limited to a very small extent of the circumscribing space; if the object to be protected and the termination of the conductor be both within this space, the conductor will lead away the whole or the principal portion of the discharge; whereas, if the conductor be not there, the object will take the whole; the former will always be the case when the conductor and the object to be protected are sufficiently near each other; and if under such circumstances any division of the discharge does occur, it may be confidently asserted that the injurious effects would be greatly increased by the absence of the conductor; but on account of the greatly superior conducting power of the lightning rods, the probability of any injury arising from this cause must be very small. If the conductor and object be too remote from each other, a discharge on the latter will not be averted by the former; but in this case the conductor has no detrimental effect, it is merely null; and if under the same circumstances the discharge fall on the conductor, it will become the sole channel of transmission of the electric discharge to the earth. The case of a conductor determining a discharge upon itself, which would not have fallen upon the object intended to be protected, and yet dividing the discharge upon such object, I hold to be quite chimerical.

But another source of danger has been prominently put forward as appertaining to lightning conductors, and has even given rise to recommendations for their prohibition. It has been observed that, when a discharge of electricity passes through a metal rod communicating with the earth, if any good, or even imperfectly conducting bodies be in its vicinity, sparks and flashes frequently appear to pass between them. These effects, when they occur, may be attributed to two distinct causes:—*1st*, the division of the discharge which thus finds a second path to neutralize itself in the earth; and *2ndly*, the induction of the rod upon insulated conducting masses in its neighbourhood. Under the most favorable circumstances for the production of these secondary effects, the energy they exhibit must be vastly inferior to that of the quantity which is transmitted through the conducting rod to the earth, and which is averted by its agency from falling with undiverted force upon the building. At the worst a small danger is substituted for a great one; but even this limited danger may be avoided by proper precautions, which have already been judiciously pointed out by removing—for instance, from the building in the vicinity of the conductor—all insulated metallic masses, or by making a conducting connexion between them and the conductor; or, what is perhaps preferable in the case of Powder Magazines, adopting Dr. Faraday's suggestion of completely detaching the conductor from the building.

I deem it needless to dilate upon these topics, after they have been so amply and ably treated in the reports of Doctors Faraday and Daniell; and will therefore only express my entire concurrence in the recommendations they have proposed. Lightning conductors, especially in countries like India, where the disturbances of electric equilibrium in the atmosphere occur with an intensity unknown in more temperate regions, may not be an *absolute* safeguard to buildings exposed to their destructive effects; but I cannot doubt that, in all cases, they will have a most beneficial result, and that when they do not avert the danger altogether, they will at least deprive the storm of a portion of the power of producing mischief it would otherwise exert.

Dr. O'Shaughnessy has referred to the circumstances which took place when the Cathedral of Strasburgh—one of the highest buildings in the world—was struck by lightning in 1843; and has adduced them as proving the dangers to which edifices are exposed even when provided with perfect conductors. It is incorrect to represent this occurrence as an accident which happened to the cathedral; for though, during a violent storm, the conductor was struck twice by lightning, no injury whatever was done to the building, not even a piece of stone or mortar was detached from it. It appears that two of the conductors terminated in a well close to a tin-man's shop, on the sides of which were ranged a great number of vessels of tinned iron and zinc, and in the corner nearest one of the conductors, long bars of iron were standing against the wall; behind the shop, by the side of the two conductors, and as M. Fargeand states, most probably touching them, there was heaped up a large quantity of lead and iron, which had been removed from the roof of the nave. This great mass of extraneous metal diverted a portion of the current from its principal direction towards the well, and determined it towards the nearest external conductors, and it passed in the form of a disruptive discharge from this mass to the bars of iron in the shop, but without doing any injury to the seven or eight persons who were assembled therein. On this Dr. O'Shaughnessy makes the following observation:— "The fact—the conclusive warning fact—that they (the flashes) occurred close to an admirable conductor, and were occasioned by this conductor, is beyond all cavil and misrepresentation." True; but had an experiment been purposely devised to divert an electric discharge from its accustomed channel, it would not have succeeded better than under the conditions which were here accidentally present; and it would be the highest degree of carelessness, now we are warned of the consequences, to allow such conditions to exist in the neighbourhood of a building. Moreover, I am disposed to believe that this effect would not have taken place had the termination of the conductor in the well consisted of a large metallic surface instead of a bar, the section of which was only about 2 inches by ½ an inch.

The circumstances relating to the establishment of the lightning conductors on Strasburgh cathedral, are, so instructive, and prove so decisively the efficiency of such protection, that I must be allowed briefly to recapitulate them. The full details given by M. Fargeand will be found in the *Annales de Chimie et de Physique*, 3 eme, Serie F. 13, p. 317.

This edifice, as might be expected from its great elevation, has suffered considerably from thunder storms. It was established by documents placed before a Committee in 1833, that for the preceding thirty years, the average expense of repairing the damage done by lightning to the cathedral was 1,000 francs per annum. To go further back, in 1759, on the 27th of July, a stroke of lightning burnt the whole of the woodwork of the roof of the church; and in October of the same year, the lightning fell three times during the same storm, on the upper part of the tower, and almost entirely divided one of the pillars of the lantern. In 1780, a project for establishing a lightning conductor, which had been submitted to the examination of Franklin and approved by the Academy of Sciences, was recommended to the Magistrates of the city, and rejected on account of the expense. In 1827 the attention of the authorities of Strasburgh was again called to the subject in consequence of the wish expressed by M. Gay Lusac, when he visited the cathedral, that this monument should be protected from the attacks of lightning by a properly disposed conductor; but the same erroneous notions which have so long prevailed called up an opposition, which prevented even a preliminary trial being made by affixing a conductor to the theatre. Things were in this state, when, on the 18th August 1833, a most violent storm broke over the city, and the tower was struck three times within a quarter of an hour; the lead, copper, iron, the mortar, and even the stone itself, were burnt and fused in many places; the hammers became soldered to the bells, and serious accidents happened from stones projected into the neighbouring streets. The damage thus occasioned drew the attention of the Administration once more to the subject, and a Committee was appointed to report on the propriety of placing a conductor on the tower of the cathedral. The Report was made and ordered to be printed; but no steps were taken to give effect to the recommendations made therein. Nothing probably would have been done in the matter, had not a more terrible explosion occurred in July 1834; one of the four turrets was cut in half, enormous stones were displaced, and numerous fragments were transported to considerable distance. The alarm spread by this accident occasioned the long rejected project to be put in execution, and in the summer of 1835 the present efficient system of lightning conductors was completed. During the subsequent seven years, it does not appear that either the building or the conductors had been struck by lightning,* and, as M. Fargeand states, it almost seems that storms had become less frequent and less intense over Strasburgh. But on July 10th, 1843, the storm above mentioned burst over the city; the lightning struck the conductor twice, without doing the slightest damage to the cathedral; and that abnormal division of the discharge occurred near the ground outside the building, which Dr. O'Shaughnessy has introduced into the discussion.

It now only remains for me to state my opinion of the plan proposed by Dr. O'Shaughnessy for protecting Powder Magazines, which is described as "a simple and certain plan, by which the Magazine will be placed in a condition in which, were it to be struck by lightning daily, still no disaster would ensue." The fallacy of the assumed principle on which the recommendation in question is founded, has been so completely shown by the simple and decisive experiments of Dr. Faraday, that it is unnecessary to add a single word to the force of that evidence. Dr. O'Shaughnessy has not adduced a single experiment in support of the efficacy of his system, but seems to have founded his opinion on theoretical views alone, to which, it appears to me, he has been led by not properly distinguishing the phenomena of electricity at rest from those of electricity in motion. I agree with Dr. Faraday that, while the new plan will have no superiority over the one formerly proposed in averting danger arising from the occurrence of sparks and flashes between the conductor and conducting bodies adjacent to it, the insecurity will be augmented rather than diminished, in consequence of the liability of flashes occurring between disconnected portions of the ramified conductor itself.

To conclude, while I repose entire, confidence in the efficacy of properly constructed lightning conductors, I am far from thinking that the discussions, to which the opposition to their establishment has given rise, have been either useless or unimportant; they have prominently indicated sources of danger, to which sufficient attention had not hitherto been paid, and have led to valuable suggestions for avoiding them.

C. WHEATSTONE.

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* The damage done to Strasburgh cathedral by lightning was formerly, almost every year, such as to occasion considerable expense. Since the rather recent period at which it has been provided with a lightning conductor, no damage has been sustained, and this item of expenditure has disappeared from the Municipal Budget.—*Arago's Meteorological Essays.* —ED.

No. 17.

LETTER FROM THE SECRETARY TO THE BOARD OF ORDNANCE, TO MR. SECRETARY MELVILL.

Office of Ordnance, 30th June 1845.

SIR,—Having submitted to the Master-General and Board of Ordnance your letter, dated the 12th instant, requesting to be furnished with information of the practice at present observed for protecting Powder Magazines in British Colonies from lightning, especially the Magazines in the West Indies and other tropical climates.

I have the honor, by the Master-General and Board's commands, to transmit to you, for the information of the Court of Directors of the East India Company, the enclosed copy of the Report of a Committee of Royal Engineers on lightning conductors, dated 3rd March 1828, and also the copy of a letter from General Mann, dated 7th July 1827, on the subject; and I am to observe that, although the principle of applying lightning conductors to all large Magazines is acknowledged, it has frequently occurred that the "practice" has not obtained, even in the tropics, for small service or regimental Magazines.

R. BYHAM.

No. 18.

LETTER FROM GENERAL MANN (ROYAL ENGINEERS), TO THE SECRETARY BOARD OF ORDNANCE.

84, *Pall Mall, 7th July* 1827.

SIR,—I have to acknowledge the receipt of your letter of the 4th instant, and whenever the Board communicate to me the answer they may receive from the Royal Society, I shall appoint a Committee of Engineers to be in communication with them on the subject of lightning conductors; in the mean time I venture to offer the following observations on their utility:—

The question itself (one upon which of late years there have been considerable doubts,) may be considered in two points of view—philosophically and practically; but the latter is that to which I should be inclined to pay the greatest attention, although the arguments that may be used under the first head, for or against the question, cannot fail to have influence on the measures which should be adopted under the second; and as the question philosophically has never, that I know of, notwithstanding the consideration given to it, been brought to any satisfactory result or uniform opinion, so the practice respecting the use of conductors must still be various and undecisive. I am, therefore, of opinion that, until something satisfactory and conclusive can be confidently decided upon, there are no sufficient reasons for disturbing or altering the present practice, and therefore that all important buildings, more especially Magazines or Laboratory Store-houses, should be provided with one or more pointed conductors, not fixed to the buildings, but separated from them, of sufficient height and at some small distance. I am not aware, whatever may have been the philosophical opinion upon the subject, that any buildings so provided have experienced any fatal effects from lightning. If this is really the case, it is better to go on as before, than to try new experiments, unless the report and proceedings of the Royal Society and Committee of Engineers should fully justify a departure from the present practice, and point out some other that may be depended on as preferable. At present, even should it be admitted that pointed conductors invite the electric fluid, still, if they also disperse it without harm, then it is rather in favor of than against the practice of using them.

GOTHER MANN.

No. 19.

REPORT ON THE SUBJECT OF LIGHTNING CONDUCTORS BY A COMMITTEE OF OFFICERS OF THE CORPS OF ROYAL ENGINEERS, TO GENERAL MANN.

March 3rd, 1828.

SIR,—Agreeably to your order that we, the undersigned Officers of the Corps of Royal Engineers, should meet and confer with the President and a Committee of the Council of the Royal Society, on the subject of lightning conductors, in reference to certain official letters and documents upon the same subject, which had been addressed to the Hon'ble Board of Ordnance, we now beg leave to report our proceedings.

Our first conference was at the apartments of the Royal Society, Somerset House, on the 20th December 1827, being the day named by you. This led to a correspondence in the form of queries addressed by us to the President and Council of the Royal Society, to which they returned answers ; and afterwards we thought it necessary to request them to favor us with a second conference, in order to discuss more fully certain details of the subject. This took place on the 21st ultimo.

As we, whose signatures are annexed to this Report, were not possessed of more than a superficial knowledge of electricity, we conceived that the object of the Hon'ble Board of Ordnance, in desiring us to confer with the President and Council of the Royal Society, would best be promoted by our soliciting information from them in regard to those points which, being of a strictly scientific nature, it exceeded the limits of our own experience and practical knowledge to decide upon.

Mr. Davis Gilbert, the President, Captain Hater, Vice-President, Dr. Young, Mr. Children, and several other scientific Members of the Council of the Royal Society, with whom we first met, and afterwards corresponded, communicated their ideas to us on this important subject with the utmost liberality. We could observe that, in certain trifling details, a little difference of opinion at first appeared to prevail amongst some of those gentlemen, as was naturally to be expected, they coming unprepared for the particular points that were referred to them ; and in consequence of our making practical objections to some few of their first ideas, they were pleased to modify them afterwards to a certain degree in our second conference, which we consider the most important and satisfactory ; for all parties then came fully prepared for the points most worthy of discussion, and at this last meeting, we were much indebted to Dr. Woollaston, who had not before been present.

The measures that ought to be adopted, and the general principles that ought to be kept in view, for securing buildings against the effects of lightning, as developed by those distinguished scientific gentlemen in their second conference with us, are as follows :—

1*st.*—That the most proper lightning conductors are metallic rods, elevated some feet above the highest ridge or summit of the building, pointed at top, with a moderately acute angle, and terminating at bottom either in water, which is the best arrangement, or in a moist stratum of earth, at some distance from the building, and that it may be useful to cause the lower end of the rod to fork out into more branches than one.

2*nd.*—That the least oxidable metals are the best conductors ; and therefore, of the common metals copper is preferable to iron ; but as the former is much more expensive, a mixed rod having the top of copper, and the remainder of iron, will answer the purpose, care being taken to unite the two metals intimately at their common point of junction by soldering, screwing one point into the other, rivetting, or otherwise. The top is recommended to be made of the more perfect metal, because the preservation of the point of a lightning conductor is of most importance.

3rd.—That an iron rod used as a lightning conductor ought to be about 1½ inch in diameter; but that rods of any other metal having greater conducting powers, if used for the same purpose, may be made somewhat slighter with the same effect; and generally that the most oxidable, and most conducting metal ought to be the thickest.

4th.—That the point, or other superficial application necessary for preserving an iron rod from corrosion will not impair its properties as a conductor of lightning, which depends more upon the mass, than on the surface of metal employed. Also, that the superficial oxidations of an iron rod, not protected by paint, &c., would be no further prejudicial than inasmuch as it diminishes the mass of perfect metal, which by degrees it may completely destroy.

5th.—That insulated conductors at the distance of 10 or 12 feet from the walls of a building, are preferable to those which are attached to the building itself. The former must, of course, be secured by fixing them to masts or poles of sufficient height. That two such conductors placed at the ends of a Powder Magazine will generally be sufficient for its protection, unless the building shall be, of more than usual length, in which case it may be proper to add two others, also insulated, one in front and one in rear towards the centre.

6th.—In case of conductors being attached to a building (which they do not absolutely reprobate, under peculiar circumstances, although they consider insulated ones better) they are of opinion that all abrupt and angular turnings ought to be avoided in changing the direction of the metallic rod, especially at re-entering angles; but that at salient angles, this may be deemed of less importance. Also that in fixing it to the roof or walls, the rod ought to be in contact with some non-conducting substance, and not with metallic cramps or holdfasts.

7th.—That it is a matter of the utmost importance to preserve lightning conductors always in a proper state of repair; for, if lightning should act on a perfect conductor constructed according to the rule before laid down, it will discharge itself harmlessly in the water or moist earth, into which the bottom of the rod is led, without injuring the building; but if the lower part of the metallic rod should previously be broken off by accident, the lightning, after playing along the upper part of the rod, may shatter to pieces any non-conducting substance that it may meet with at the point of fracture.

The above seems to be a strong reason for preferring insulated to attached conductors, for if the former be broken by accident, it can only lead to the downfall of the masts or poles, to which they are attached, whereas a like accident happening to the latter, might occasion great injury to the buildings with which they are connected.

8*th*.—That metallic ridges, hips and gutters, such as are used on the roofs of buildings, if connected with metallic water-pipes, leading into drains below and outside of the building, may answer the purpose of lightning conductors, and tend to the security of a building, provided that the metal used be sufficiently substantial, to prevent its being fused by lightning.

9*th*.—On the above principle they do not consider the practice of covering roofs with iron plates tinned over, as at Quebec, to be in any respect injurious to the safety of buildings, provided that the metallic water-pipes be kept perfect, and that they do not finish abruptly before they reach the ground.

10*th*.—Attending to the same precaution also, they do not object to the use of metallic ridges, hips, gutters, &c., on the roofs of Powder Magazines; but when this precaution is not taken, they consider metal on the roofs only, and not connected with the ground, as being highly objectionable.

11*th*.—Having made known to them the prevailing practice of covering the doors and window-shutters of Powder Magazines with sheet copper, to prevent accidents by external fire, they see no objection to this arrangement.

12*th*. Having shown them the model of the new barracks in the West Indies, in which a more than usual quantity of iron is employed and in which the ridges, hips, and gutters of the roof are of metal, they are of opinion that if a continuity of metal from the roof to the ground be obtained, by leading four metallic rods, from the base of the lower tier of iron columns of the verandah, one at each angle of the building, and terminating them in water or in moist earth, as before recommended, that there will be no more danger of those barracks being injured by lightning, than if there were no iron used in the construction.

Having thus stated the valuable information received by us from the President and Committee of the Council of the Royal Society on this important subject, we beg leave to add, with much diffidence, a few observations of our own, together with the inferences drawn by us from the above opinions.

In the first place, we consider that the buildings most apt to suffer injury by lightning are those having spires, or very high pinnacles, or those situated on very commanding eminences, without any other objects overtopping them, especially if the buildings so situated should be constructed of combustible materials.

Fortunately these circumstances so very seldom apply to Powder Magazines which are of a plain form, without projections, of a substantial construction, not liable to be set on fire, and usually placed in low or sheltered situations; that we consider them as being perhaps of all buildings the least liable to accidents from lightning; but taking also into consideration the great injury to all surrounding objects that might arise from the explosion of Powder Magazines, we think that no reasonable precaution ought to be omitted for their security, and therefore that they ought to be provided with metallic rods as lightning conductors, over and above the precaution of having a continuity of metallic matter, when such is used on their roofs from thence to the ground outside.

We beg further to suggest, that it may sometimes be expedient to use metallic rods as conductors for the protection of public buildings of a very inflammable nature or of those having very lofty spires, although not containing gunpowder, provided that such buildings be situated on high ground known to be frequently visited by lightning, and as insulated conductors could not generally be used, under the circumstances supposed, we beg leave to recommend that the metallic rod shall either pass through holes in projecting plugs of hard wood, or stones attached to the walls, or that a piece of wood may be interposed between the rod and the iron cramps that connect it with the walls.

In respect to all other public buildings, with the exception of those that have been specified, we conceive that lightning conductors may generally be dispensed with, even in countries in which Thunder Storms are more frequent and dangerous than in England, provided that substantial iron pipes be used to guide the rain water from the roofs into external drains below, on the principle previously explained. We prefer iron to lead, as being not only cheaper and less liable to be stolen by ill-disposed persons, but also from a much more intense heat being required to fuse the former metal. If, however, good leaden pipes be already fixed to any Government building, we do not recommend their being removed, so long as they shall continue in repair.

As it appears to us that the absolute risk to which buildings are exposed from lightning is a practical question, rather to be determined by experience than by reasoning, and that not only certain countries, but even certain districts of the same country, and certain spots of the same district, may be exposed to much greater risk than others. We beg leave to conclude by respectfully suggesting that the Commanding Engineers at home and abroad should be directed to enquire into and make a detailed report of all accidents by lightning, affecting buildings, at or near their respective stations; describing also the peculiar construction of the building struck or injured but noting more especially the nature and arrangement of the metallic matter contained in it, and that their Reports shall not only be prospective but retrospective so far as they can ascertain any such facts with accuracy.

A correct record of accidents of this nature, transmitted from all parts of His Majesty's dominions, would enable the Engineer Department to recommend, and the Hon'ble Board of Ordnance to decide upon, the measures that appear most desirable for the protection of Government buildings against lightning, as well as on the most judicious construction of public edifices, with a view to that object, in reference to climate and situation, it being understood that the precautions proper in one situation might involve a superfluous expense in others.

Under this view of the subject also, we humbly conceive that in common public buildings, not containing explosive or inflammable stores, any style of construction, which is the most economical, and which has been proved by the long experience of any district in which it has been generally used not to be liable to accidents from lightning may still be adhered to in that district, notwithstanding that the arrangement of the metallic matter in such style of building may not be in strict accordance with the rules suggested by the science of electricity; but in all cases in which the expence would not thereby be increased, there can be no doubt of the propriety of making the metallic parts of every public building act as lightning conductors to the same, by establishing a continuity of metallic matter from the roof to the ground on the principle that was before explained.

C. W. PASLEY, *Lieut.-Colonel.*
G. BUCHANAN, *Lieut.-Colonel.*
J. M. F. SMITH, *Captain.*

No. 20.

LETTER FROM THE HONORABLE COURT OF DIRECTORS TO THE GOVERNOR GENERAL OF INDIA IN COUNCIL.

London, 17th September 1845.

REPLY TO MILITARY LETTER FROM BENGAL, 14TH FEB. 1845.

Forward papers on the subject of lightning conductors, including a report on the subject from Dr. O'Shaughnessy, and stating that pending the receipt of instructions, further application of lightning conductors to Powder Magazines has been suspended.

1. Immediately on the receipt of this letter, a copy of it and of its accompaniments was placed in the hands of Professors Faraday and Wheatstone, with our request that they would each furnish us with a report of his opinion on the views and sentiments which had been expressed on the subject in India, as contained in the collection received from you. We also addressed the Master-General and Board of Ordnance, requesting to be furnished with information of the practice at present observed for protecting Powder Magazines in British Colonies from lightning, especially the Magazines in the West Indies and other tropical climates.

2. We now forward copies of the replies we have received, from which you will learn that the Professors above named are both decidedly of opinion that conductors, according to the plan approved by Professors Faraday and Daniell, as already communicated to you, should be attached to all Powder Magazines. You will also learn from the reply of the Board of Ordnance and its enclosure, that the principle of applying lightning conductors to all large Magazines is acknowledged and acted upon.

3. We have now no hesitation in communicating to you our desire that lightning conductors, according to the plan above mentioned,

may be forthwith applied to all station Powder Magazines at the three Presidencies.

4. Although the views of Mr. O'Shaughnessy on this subject are not adopted, we observe with satisfaction the remark of Professor Wheatstone that " whilst he reposes entire confidence in the efficiency of properly constructed lightning conductors, he is far from thinking that the discussions to which the opposition to their establishment has given rise, have been either useless or unimportant; they have prominently indicated sources of danger to which sufficient attention had not hitherto been paid, and have led to valuable suggestions for avoiding them."

5. You will be pleased to communicate a copy of this despatch and of its enclosures for the information and guidance of the Governments of Madras and Bombay.

Appendix.

Comprising a few useful Extracts of a practical tendency from Sir William Snow Harris's Work on Thunder Storms.

Note A.

NATURE OF LIGHTNING RODS.

The damage sustained by buildings and ships in thunder-storms being invariably found to occur in the spaces where good conductors of electricity cease to be continued, it became an important question in practical science how far it would be desirable to provide at once a continuous line of conduction, through which the electrical discharge might be transmitted without any intermediate explosion, and consequently without damage to the general mass,—an idea first suggested by the American Philosopher Franklin, and since carried effectually into practice under the form of a lightning rod.

The application of such a rod to a building or ship, is evidently equivalent to the uniting into a continuous conducting train all the detached metallic masses between which damage ensues, and in the case of particular buildings, into the construction of which such masses do not enter, it supplies the degree of conducting power requisite for their safety. A conducting rod, therefore, in whatever way it may be applied, is to be considered merely as a means of perfecting the conducting power of the whole mass so as to admit of intense discharges of lightning being securely transmitted, which otherwise would not pass without intermediate explosion and damage; for it must never be forgotten, as an important feature in the consideration of this question, that the materials of which buildings and ships are composed, are, for the most part, such as come under the denomination of conductors; the whole fabric is, therefore, to a greater or less extent, an electrical conductor. Now, the chance of its escaping damage from a discharge of lightning increases with its power of transmitting the electrical action by which it is assailed. If we could suppose a ship or building to have a perfect conducting power in all its parts, or if we imagine it to be metallic throughout, then damage from lightning would be unknown. Thus discharges of lightning struck repeatedly on the iron steam boat which accompanied Lander in his last attempt to explore the interior of Africa, without producing the slightest effect on it, whilst vessels built of wood and metal were damaged. The great object, therefore, to be attained in the application of lightning conductors to the defence of buildings and shipping from lightning, is to bring the general mass as nearly into this state as possible.

NOTE B.

CONDITIONS REQUISITE TO PERFECT SECURITY.

The general principles to be kept in view in the application of lightning rods, are these. The rod should be made of the best conducting substance; it should be continuous, and have great electrical capacity, and the metal of which it is composed should expose as great an extent of surface as possible, consistently with strength and durability. Its upper extremity, which should project freely into the air, should be pointed and may be triangular, somewhat similar to a bayonet. In cases where metallic vane-spindles or other points exist, it may commence from these. It should be led as directly as possible along the building, and be fixed to its walls. It should terminate immediately under the surface of the ground in two or more branches passing out in any convenient direction; these branches should, if circumstances permit, be connected with a spring of water, a drain, or some other conducting channel. It should be applied immediately to the part to be defended, and not at a short distance from it, and should be so applied that a discharge of lightning falling on the general mass could not possibly find its way to the ground by any circuit of which the conductor did not form a part; that is to say, the conductor should be united with all the great masses of metal in its vicinity, which offer other possible lines of discharge: by this arrangement, no more of the discharge could pass in the direction of such masses than could be transmitted without damage.

NOTE C.

CONDUCTING POWER OF VARIOUS METALLIC SUBSTANCES.

The lightning conductors first employed were usually of iron, and consisted of small rods or chains. Iron, however, is not the best metal for this purpose, its conducting power being inferior to zinc, and far below that of copper. Dr. Priestley observes, that an electrical explosion which only melts a copper wire of a given diameter, would quite dissipate an iron wire of twice that diameter. "Copper," he says, "would therefore be a much greater security for a building than iron; but then it is more expensive." For certain small quantities of electricity, however, all the metals are equally efficient, or nearly so; it is in the transmission of intense charges that the differences become manifest. The conducting power of copper in such cases is full five times that of iron, and twelve times that of lead.

NOTE D.

LAWS OF ELECTRICAL CONDUCTION.

The heating effect of the same, or different quantities of electricity, on metallic wires of the same or different diameters, is as the square of the passing quantity of electricity directly, and as the square of the diameter of the wire inversely.

Thus the heat developed by a passing shock is four times as great when the quantity of electricity is doubled, and only one-fourth as great when the diameter of the wire is doubled. A metallic rod, therefore, of twice the diameter, conducts twice the quantity of electricity with the same development of heat. Taking the heat evolved as proportionate to the resistance, we may conclude that the conducting power of a metallic body varies with the area exposed in cutting it transversely to its length ; that is to say, with the area of its section, since this is proportionate to its solid contents.

In estimating the resistance of a metallic body to the transmission of a shock of electricity, we have also to take into consideration the distance traversed. Now the resistance to electrical transmission through a metallic wire, has been found to increase with the length of the wire ; that is to say, the resistance to the transmission of the charge was twice as great when the length of the conductor was doubled ;*—a law observable from one hundred up to one thousand feet in length. A lightning conductor, therefore, should have its dimensions increased, when required to be of considerable extent.

The explanation of the above general laws seems to be this ; supposing a given quantity of electricity to fall on a single metallic particle, and to experience a given resistance to its progress, then this resistance would be diminished by placing a second particle by the side of it, for the charge would be divided between the two. If two other particles were added, we may conceive it to be still further reduced in proportion to the number of particles sharing in the conduction. Now, in the case of the section of a metallic wire, the diameter of which is double that of another, there are four times the number of particles—hence the resistance with the same quantity of charge is reduced to one-fourth. In a similar way, it may be shown that by increasing the length of the conductor, we continually increase the number of particles to be passed through,—hence the resistance through twice the length will be twice as great; through three times the length, three times as great, and so on. In the case of the quantity of electricity being increased, we have the resistance dependant not only on the increased charge, but also on its increased force. Thus a particle of metal conducting a double quantity of electricity is subject to a double force, since it is quite reasonable to conclude that the forces with which the opposite electrical powers tend to unite, would increase with the amount of disturbance.

Note E.

MECHANICAL EFFECTS OF THE ELECTRICAL DISCHARGE.

But it is not only the heating effect of the discharge we have to consider ; it is necessary to take also into account its more mechanical effects,—indeed, it is the expansive action which produces the great mass of damage by lightning so commonly observed. If a powerful shock of electricity be transmitted by a fine wire, the wire will very often appear crippled throughout its length, and will exhibit a series of zig-zag creases. And if a similar shock be passed between two metallic balls in a confined portion of air, the air will be caused to expand with great violence, so as to frequently burst open the containing vessel. Light bodies such as wafers will become dispersed in all directions, when exposed to the expansive effect produced by the electric shock in passing through a short interval of air.

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* These different results were determined by the Author in various investigations, published so long since as the year 1825, and they have since been confirmed by other inquirers, both in this Country and on the Continent.

In the application of lightning conductors to buildings, therefore, we have to consider the effect likely to be produced on them by the mechanical action of the shock, by which they may be disjointed, twisted, or rent asunder in various ways. Thus the small conductor of linked brass rod, at Charles Church, Plymouth, struck by lightning in December 1824, was literally torn in pieces and disjointed, and many of the links twisted into the shape of the letter S. A part of the small wire rope applied as a conductor to the Hotel des Invalides at Paris was broken into small pieces an inch or more in length, and scattered in all directions by the lightning which fell on that building in June 1839. This conductor consisted of about twenty iron wires twisted together as a rope; the lead surrounding the lantern was torn up and scattered, but without any signs of fusion.

The intensity of electrical accumulation having been found to decrease in an inverse ratio of the square of the opposed surfaces, some electricians were led to imagine that extent of surface was the great desideratum in the application of a lightning conductor This decrease of intensity, however, does not affect the conditions of conduction as regards the heating effect of the discharge, for whether the quantity of electricity be accumulated on a large extent of surface, or on a small one, the heating effect, when the discharge does ococur, is always the same. Whatever may be the distance at which the neutralization of the forces begins, they always unite with precisely the same degree of power, the quantity of electricity being the same.

This question, so frequently discussed, has not been fully appreciated in all its details, for although quantity of metal is an essential condition of a lightning rod, yet it is likewise desirable to place the metallic particles under as great an extent of surface as may be consistent with strength and durability, in order to keep down the intensity of the shock, and diminish the mechanical action. We may, in fact, for the moment, consider a conductor, while in the act of carrying off a charge of lightning, as an electrified body. Its electrical intensity, therefore, is very much less with a large surface than with a small one; hence, by extent of surface, we diminish the activity of the passing charge, and tranquillize its mechanical effect on the conductor. Thus, we find in a variety of cases of damage by lightning that the passing charge, in striking on large expanded sheets of metal, has become comparatively tranquil, and has been traced no further, whilst in striking on larger masses of metal exposing but a small surface it has assumed an intensely active state. The flash of lightning which struck His Majesty's ship Badger, lying in the Medway in August 1822, vanished, after striking upon the copper lining of the galley, although just before it had penetrated the mast, rent the copper, and melted the lead over the heads of two large bolts in the deck beams.

Provided the quantity of metal be present, the form under which we place it is evidently of no consequence to its conducting power, since it would be absurd to suppose that a mass of metal, under any form, did not conduct electricity in all its particles; indeed, we know that it does so, and that it is impossible to fuse by electricity a portion only of a homogeneous metallic plate of uniform thickness. Again, if the heating effect of a given quantity of electricity on a metallic wire be measured, and then the wire be rolled out into a flat surface, or otherwise drawn out and placed under the form of two or more smaller ones, still the same heat will be evolved when conducting the same charge.* There is consequently no disadvantage in giving a lightning rod as much superficial capacity as possible as regards conducting power, whilst, on the contrary, the diminished intensity attendant on it is very advantageous. This effect of superficial conductors appears to depend on the removal of the electrical particles further out of the sphere of each other's influence. In a dense solid rod they may be supposed to be in a state of compression in each other's way, as it were, whereas, by expanding the same quantity of metal into a larger surface, we immediately free them from this condition, and allow them greater space.†

In order, therefore, to resist the heating effect we require quantity of metal to restrain the electrical intensity, and to diminish the mechanical force we require extent of surface. The distinction is nice, but it is a very important one.

NOTE. F.

HOW FAR DOES THE PROTECTING POWER OF A LIGHTNING ROD EXTEND?

It is not easy to assign the limit of the protecting power of a conductor. The French philosophers consider it will afford protection over a circle equal to twice its radius‡ This, although possible in certain cases, is by no means a general truth. All the experience we have of the operation of conductors on discharges of lightning, tends to the conclusion that they have no influence whatever in determining the course of such discharges further than arises out of the circumstance of their furnishing an easy line of conduction. That they do not always afford protection over any considerable distance, is clear from the following cases.

Although these cases evidently throw doubt on any theoretical calculation as to the limit of distance, within which a pointed lightning conductor will afford protection and confirm in a remarkable way the views we have taken of electrical discharges from the atmosphere; still they bear a small proportion to the great mass of instances in which lightning falling on buildings has struck on the conductors attached to them, especially in such buildings as have any elevated parts, as the spires of churches, central cupolas and domes, columns, and the like. Even in ships, the exceptions are by no means numerous, although it is certainly very undesirable to trust to a conductor on one of the masts only. To meet, however, the great exposure of large ranges of straggling buildings, it evidently becomes requisite to distribute connected conducting lines through them in any convenient way, and to unite these lines with pointed conductors placed at given parts of them. Thus, in such a building as that represented in the annexed figure pointed conductors should be applied from the

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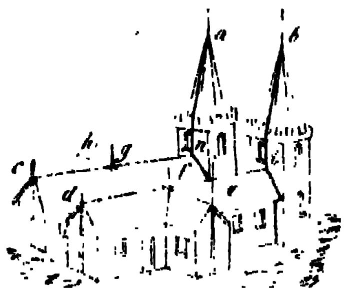
* Trans. Royal Society for 1827.

† See Phil. Trans. for 1834 and 1836, p. p. 232 and 450, for some further inquiries on this point by the Author.

‡ Annales de Chirme et de Physique, Vol. 26.



points, a b c d e f g h, &c., and these conductors should be tied into one general whole by bands of metal, c n d t e h, &c.

Note G.

WHETHER LIGHTNING RODS ATTRACT LIGHTNING.

Amongst the objections made to the employment of lightning rods, there appears to have been none so popular, and at the same time so plausible, as this, *viz.*, that by setting up pointed conductors we invite lightning to our buildings, which otherwise would not fall on them; that should the quantity of electricity discharged be greater than the rod can carry off, the redundant quantity must necessarily act with destructive violence; and that since we can never know the quantity of electricity which may be accumulated in, and be discharged from, the clouds, it is not improbable but that any conductor which we can conveniently apply, may be too small for the safe conveyance of such a charge.

Although the advocates of these opinions have never adduced any substantial fact, or any known law of electricity, in support of them, although they have never, by any appeal to experience, shown that buildings armed with lightning rods have been struck by lightning more frequently than buildings not so armed, nor demonstrated any single instance in which an efficient lightning rod, properly applied, has failed to afford protection—nevertheless such views have been commonly entertained, indeed so strenuously have they been insisted on, and that too by persons of education and influence, that the Governor General and Council of the Honorable the East India Company were led to order the lightning rods to be removed from their powder magazines and other public buildings, having in the year 1838 come to the conclusion, from certain representations of their scientific Officers, that lightning rods were attended by more danger than advantage, in the teeth of which conclusion, a Magazine at Dum-Dum and a Corning-house at Mazagon, not having lightning rods, were struck by lightning and blown up.*

In a work on Canada, published so lately as the year 1829,† we find the following passage :—"Science has every cause to dread the thunder-rods of Franklin ; they attract destruction, and houses are safer without than with them. Were they able to carry off the fluid they have the means of attracting, then there could be no danger ; but this they are by no means able to do." Assertions such as these, appealing as they do to the fears of mankind rather than to their dispassionate and sober judgment, have not altogether failed in obtaining that sort of temporary favour which so frequently attends a popular prejudice, promulgated without reason, and received without proof. Not only is the idea that a lightning rod invites lightning unsupported by any fact, but it is absolutely at variance with the whole course of experience.

The notion that a lightning rod is a positive evil, appears to have arisen entirely out of assumptions, and a partial consideration of facts. Thus, in consequence of the track of a discharge of lightning being always determined through a certain line or lines, which upon the whole least resist its progress, it has often been found to fall in the direction of pointed metallic bodies, such as vanes, vane-spindles, iron bars, knives, &c. The instances in which those bodies seem to have determined the course of lightning have been carefully recorded, the phenomena being peculiarly striking and remarkable; but, on the other hand, no attention has been given to those instances in which lightning has altogether avoided such bodies, and passed in other directions. Now, it will be found, as we shall presently show, that the action of a pointed conductor is purely passive. It is rather the patient than the agent; and such conductors can no more be said to attract or invite a discharge of lightning than a water course can be said to attract the water which flows through it at the time of heavy rain.

NOTE H.

LATERAL DISCHARGE.

The phenomenon, termed lateral discharge in electricity, has frequently engaged the attention of electricians. So long since as the year 1780, Priestley found that a metallic rod would, at the instant of discharging an electrical jar, emit a spark.

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* Correspondence with the Honorable Board of Directors; Professor Daniell and Dr. O'Shaughnessy.

† Three Years in Canada. By F. McTaggart, Civil Engineer in the service of the British Government.

At a more recent period, Professor Henry, of New York, in following up Van Marum's experiments upon small wires exposed to a current from the electrical machine[*] obtained many new and curious results; he showed that sparks might be obtained from such wires, of an intensity sufficient to influence hydrogen and produce other powerful effects.

These results have been classed under the general head of lateral discharges, and have been adduced by many writers, without any very profound investigation of the subject, as a ground of objection to the employment of lightning rods. They have neither identified the phenomena with the conditions of the electrical discharges from the atmosphere, nor have they brought forward a single case in which lightning rods, in the act of transmitting discharges of lightning, have thrown out such lateral explosions, and thereby caused damage to surrounding bodies; so that the conclusion arrived at that lightning rods are likely to damage buildings by a lateral discharge of electricity, rests on no higher authority than that of a mere assumption.

Biot examined this species of electrical action, and came to the conclusion that, the spark observed to take place from the discharging circuit of an electrical jar, is due to a small quantity of redundant electricity which always exists on one or other of its coatings, and not to the discharge.

Priestley, so long since as the year 1770, had arrived at nearly the same conclusion,[†] and in the *London and Edinburgh Journal of Science for December* 1829, will be found a further investigation of this subject by the Author. It is there proved—

First.—That at the time of the discharge no portion of the neutralizing forces escapes from the discharging rod under the form of a lateral explosion.

Secondly.—That the spark supposed to be a lateral discharge produced by the passing shock, is as readily obtained *after the system has become neutralized* as at the apparent moment of discharge.

Thirdly.—That the kind of electricity of which the spark consists, varies with the electricity in excess upon either of the coatings.

Fourthly.—That the magnitude of the spark varies with the extent of surface upon which the accumulation has taken place; so that a given quantity of electricity accumulated on several jars does not produce a residuary spark equal to that obtained from the same quantity accumulated on one jar only, notwithstanding the heating effect of the accumulation remains in both cases the same; and further, that double or treble the quantity of electricity discharge from double or treble the number of equal jars, gives a residuary spark of no greater magnitude than a single quantity discharged from a single jar, and that, as a double or treble quantity of electricity, in passing through a discharging rod, would certainly give out a spark of greater intensity than a single quantity, were

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Tilloch's Magazine and Reports of British Association, Volume VI.

[†] Phil. Trans., Volume LX., p. 192.

this spark a lateral explosion, it is evident that the phenomenon termed lateral discharge is not referrible to any action of either of the neutralizing forces in their passage through the rod.

"I never observed," says Priestley, "the least attraction of bodies towards the brass rod through which the explosion passed, though I employed several methods which could not fail to show it. I could not find that the explosion of a battery, made ever so near a brass rod, ever disturbed its electrical state, for when I insulated the rod, and hung a pair of pith balls on the end opposite to that near which the explosion passed, I found the balls were not the least moved."* The application of this phenomenon, therefore, termed the lateral explosion, to the case of a lightning rod, is not warranted by the simplest experiments.

In the numerous instances in which lightning has been discharged into the sea by the bolts in the solid timbers and planking of ships, we do not find any trace of a lateral discharge; although in large ships these bolts are several feet in length.

The small discharges thrown off by a wire leading from a ball in the act of receiving dense sparks from an electrical machine, result from the same species of action; the electricity accumulated on the conductor operates by induction upon surrounding bodies, but more particularly the nearest. Any secondary conducting substance, therefore, opposed to it completes the terminating surface of a charged system, so that the air between the opposed surfaces becomes charged. But in this process electricity is displaced from the wire by induction, and will strike off, as in the former case, on free conducting bodies, and this will continue so long as sparks pass between the two conductors. That is, so long as a succession of charges and discharges continue. It is doubtful whether there really be a current discharge in this wire at all: its condition is altogether dissimilar to that of a lightning rod. Besides these, there are many other circumstances, contingent on this experiment, which greatly complicate the question, for since the great conductor of the machine operates by induction upon the table, floor, and walls of the room in which the experiment is performed, we may elicit sparks from gas pipes and wires leading to the earth, although in no way connected with the receiving ball. The nature of these sparks will depend on the negative or positive induction on the floor, or other surfaces, by the positive or negative conductors of the machine. If the small wire from which the lateral explosions, as they are termed, proceed, be connected directly with the machine, these phenomena disappear; for the accumulation on the conductor is prevented from reaching any great intensity—hence, in order to obtain this species of electrical discharge in any force, it is requisite to employ disruptive discharges between opposed conductors, and the larger the surface of the charged conductor, the greater is the effect produced.

It has, however, been contended, that although no lateral explosion should occur from the passage of the neutralizing forces, yet that the great excess of electricity in the charged cloud may produce it: "because, if the flash brings down only enough to compensate the induced condition of the earth, as it exists before the discharge, it will bring down more than the earth, in its then condition, has a capacity for."* All this, however, is extremely hypothetical: we have seen why it is that any excess remains, after the discharge of an electrical jar,—it is simply because other bodies share in the induction, and all the force is not exerted between the coatings; but in as much as this condition does not apply to the clouds and earth, it is very possible that the forces between these, may exactly compensate each other without any remainder, hence it is by no means proved that after an atmospheric discharge, the excess in question would exist, at least not to any extent, and if it did, it remains to be shown that it could discharge upon a body, not having a "capacity for it," that is, upon a body in which an equivalent opposite state could not be induced. To imagine this, is to cast aside all the known laws of electrical charge: if, therefore, such an excess remain, it can only operate by a secondary discharge in a way perfectly analogous to the preceding, that is, by inducing a secondary disturbance; but this it could perhaps as well effect at first, and leave no remainder. Hence there would be either no excess of electricity in the clouds after an atmospheric discharge, or otherwise, if it existed; it would remain there until it induced in some other point of the earth's surface an opposite force, equivalent to produce disruptive discharge, that no redundant electricity passes over at the moment of discharge is quite demonstrable; for if a charged jar be placed on an insulated conducting base, and be discharged by a curved rod held by a glass handle, cautiously brought up from the outer coating to within a striking distance, then, although a considerable excess remains in the jar, not any excess will be found on the conducting table, if the jar be removed from the table by its insulating interval, without touching the outer coating.

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* Priestley's History of Electricity, p. 683.

The truth or fallacy, however, of particular views of this kind, is after all best appreciated by a careful examination of the laws of electrical discharge, observable in great natural operations.

We have seen that a lightning rod is a discharging conductor placed immediately between the terminating planes of a charged system, in which all the surrounding bodies are similarly involved: but this is not the condition of a wire placed beyond the system, where it in no degree contributes to the neutralization of the opposed electrical forces. Consequently we find, on appealing to the experience of nerly a century, that not a single case can be adduced in which a lightning rod, in the act of transmitting a heavy charge of lightning, has thrown off a lateral explosion on semi-insulated masses near it.

NOTE I.

DIVISION OF THE CHARGE.

Although there is no instance on record of an isolated lateral explosion of electricity from a lightning rod yet we find instances in which the discharge has divided between the conductor and other metallic bodies in connexion with the earth. As these cases have been also called "lateral discharges," it will be requisite to examine them. But before we proceed to the consideration of such cases, it may be as well to define clearly the difference between a division of the passing shock upon other lines of conduction near the conductor, and mere explosion of electricity. This is the more necessary, because those who have written on the subject, have never explicitly stated, what they really mean by lateral discharge as applicable to the action of a lightning rod.

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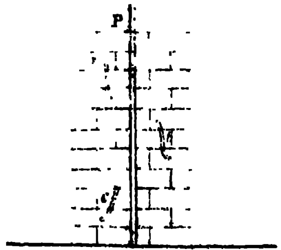
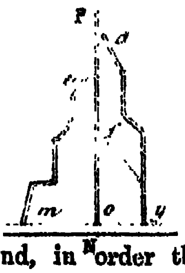
* Proceedings of the London Electrical Society, December 20, 1824.

Let P N represent a lightning rod, and *a b c* detached metallic masses employed in the construction of a building, such as cramps or other fastenings, and near which the rod passes. Then, in the absence of the rod, these metallic bodies *a b c* are in a position to operate as so many stepping stones for the electrical explosion, by which its course would be facilitated from the highest points of the building to the earth. Now directly we apply the rod P N we supersede the action of these masses, as so many points in a possible line of discharge, and prevent the damage which we have shown would necessarily ensue between them. The only question, therefore, remaining for our consideration in such cases is this—Can the bodies *a b c* elicit from the conductor P N at the instant of its transmitting a heavy discharge of lightning, a destructive lateral explosion upon the parts of the building in which they happen to be placed? This is the legitimate and fair definition of lateral discharge as applicable to a lightning rod; and we have proved, both by a copious induction of facts, and by an appeal to experiment, that there is no such effect produced in the progress of either natural or artificial disruptive discharge.

The possibility of the discharge dividing in its course, between the rod and metallic bodies in good conducting connexion with the earth, is quite another question. Thus, let *e m d y f y* be metallic pipes or other conducting substances, terminating either directly or indirectly in the earth at N in common with the lightning rod P N. And suppose these substances to commence from, or to be continued through some points *d e f* very near the rod; then, if from the small capacity of the rod, or any other casualty, the resistance in the direction of these points *d e f* should happen to be less, or even equal to that in the direction of the rod P N, the charge, as already shown, is almost certain to divide upon the additional circuits, *d e f*. Hence it is that lightning rods should be united to all the metallic circuits in a building which lead to the ground, in order that all chance of destructive explosion between the conductor and such circuits, may be avoided.





NOTE J

CONCLUDING OBSERVATIONS

Upon a review of what has been advanced in the course of these pages relative to the nature of thunder-storms and the operation of lightning rods, it appears that buildings and other elevations are struck and damaged by lightning only in consequence of their being points in one of the terminating planes of a great electrical disturbance in the atmosphere; not from any property of attraction for the matter of lightning inherent in the substances of which such elevations are composed: that lightning rods remove by the aptness of their parts, the resistance experienced by the electrical discharge in moving through less perfect conducting matter; and hence, by allowing a tranquil and free neutralization of the opposite electrical powers, they prevent the damage attendant on an obstructed action: that the operation of such rods being of a purely passive kind, they can no more be said to invite or draw down lightning upon the building to which they are applied than a common pipe can be said to draw down or invite the rain which flows through it: that such a passive property in [illegible] argument against their general use; that since lightning rods act only in transmitting as much electricity as falls on them, they cannot be prejudicial to buildings, but must, on the contrary, by a rapid annihilation either of the whole or part of the force in action necessarily contribute to its security: that lightning being nothing more than the electrical discharge moving through [illegible] matter under an explosive form, the tendency of a lightning rod is to deprive the discharge of this form from the instant it falls on the point of the rod, and finally by converting it into an evanescent current through matter calculated to [illegible] it, [illegible] to annihilate it as lightning altogether.

In the treatment of this question it was not possible to avoid a frequent appeal to electrical action, on the great scale of nature. If, therefore, the remarkable instances quoted, of lightning striking on buildings and ships, should appear to be somewhat numerous, and to be treated of in too great detail, yet it must be recollected, that it is only by pursuing such a course that we can hope to arrive at deductions worthy of confidence. Hence it is, that in the progress of these inquiries we have been led to adhere carefully to a series of well authenticated facts, and by keeping strictly within the safe path of inductive science we have endeavoured to throw some further light on a subject of very great public importance, which has not been generally or fully appreciated. With respect to certain prejudiced views and opinions which have been entertained of the operation of lightning rods, we trust to have made it appear that such opinions are founded on no sound basis whatever, and that a judicious application of pointed conductors both on land and at sea, is not only desirable, but is in a great variety of cases, quite essential to the preservation of buildings and ships from the ravages of lightning.